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REPLACEMENT ORE-BODIES AND THE CRITERIA FOR THEIR RECOGNITION.[1]

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Part I. History. Forms of Ore-bodies. Rocks Replaced.

INTRODUCTION.

Historical Review.

Of recent years our ideas concerning many phases of the formation of deposits of the metals have made rapid advances and the processes involved in their origin have been rendered much clearer by careful study. We now recognize that the fundamental distinction in the larger grouping of metalliferous deposits is between those which have been formed contemporaneously with the enclosing rock, and thus are part and parcel of it, owing their origin to the same set of processes which have produced the rock itself, and those which have in some way been introduced into the country-rock after (and generally long after) its solidification in its present form. To the first group the term "syngenetic" has been applied, to the second, "epigenetic,"—words which may be translated into simpler language as *contemporaneous* and *subsequent*. With the second, or epigenetic group, this discussion is exclusively concerned. In this group, if the enclosing rock is an eruptive, such as granite, it was a granite in all essentials as it now exists *before*

[1] Paper read before the Canadian Mining Institute, Toronto, March 2, 1910.

any mineral deposit was formed in it. If a sediment, it was already consolidated as limestone, sandstone, shale or other sedimentary rock, before it was invaded by the agents which formed the ores now found in it.

In order to find a resting-place in solid rock-masses, metalliferous ores must in some way gain an entry. Either the space which they now fill must have been open for their entry, or the rock-material must have been in some way expelled to make room for them. Pošepný[1] has expressed this self-evident fact most admirably.

"With relation to the xenogenites (epigenetic) or mineral deposits the first question concerns the space which every secondary mineral or mineral-aggregate requires to establish its existence. It must either have found this space waiting for it, or it must have made room by driving out an original mineral."

In the earlier years of the study of ore-deposits the space was generally considered to have first existed in the rock, forming a receptacle in which the deposition of foreign mineral substance could go on. Fissure-veins, long tacitly regarded as the prevailing type of epigenetic deposit, did much to strengthen this view. Deposits now believed not to be cavity-fillings were then little understood; and attempts to explain them always found expression in terms of cavity-fillings. The further classification of epigenetic ore-deposits depended largely on the form of the cavity which received the deposit. When disseminated particles of mineral foreign to the country-rock were found in the rocks adjoining fissures, or in large disseminated masses about little cracks, they were called impregnations, and were regarded as due to the invasion of ore which had migrated to limited distances from the conduit and filled preëxisting spaces in the rock. No account was taken of the fact now known, that the porosity of some rocks in which such impregnations are found, as for instance the granites adjoining the tin-veins of Cornwall, where such deposits are called Carbonas, was less than the volume of the minerals introduced into the rock.

[1] "Genesis of Ore Deposits," *Trans. of the Am. Inst. of Mining Engineers*, Vol. XXIII., p. 207.

Great irregular masses, wholly enclosed in limestone, such as those of Leadville, Colo., Eureka, Nev., and elsewhere, which were evidently epigenetic in character, but had not found simple fissures for a resting-place, were explained as filling spaces of dissolution, *i. e.*, caverns in the limestone which had been dissolved out by percolating waters, caverns which had their analogues in the Mammoth and Wyandotte caves in Kentucky and Indiana.

The words of Arnold Hague, as late as 1891,[1] relating to the great irregular deposits of Eureka, Nev., are interesting in this respect:

"A study of these channels and their intricate connections tends to the belief in the theory of pre-existing caves and underground water courses before the introduction of ore... it is most difficult to see how such vast accumulations of these sulphides could have been formed in any other way than in the pre-existing caves and openings. Any theory with which we are acquainted of chemical and physical replacement of the limestone or dolomite seems wholly inadequate to meet the necessary conditions. Pseudomorphs of galena and pyrites after calcite have been described as mineralogical curiosities and possibilities, but nowhere have they been found in large quantities in any mine, and so far as the writer is aware they have never been recognized at Eureka.... They (*i. e.*, the ores) were for the most part deposited as sulphides in pre-existing caves and cavities."

Newberry, writing in 1880, says:

"The Leadville ore-bodies were undoubtedly accumulated in vacant spaces formed by the solution of limestone."[2]

At this stage, the idea which had suggested itself long before with relation to the silicious casts of fossils, silicified wood, etc., began to be applied to the formation of ore deposits. It had been recognized by mineralogists for many years that crystals of one substance could be altered chemically into a mineral of wholly different chemical composition and still retain the form of the original mineral. Such crystals were called pseu-

[1] Hague, "Geology of the Eureka District, Nevada," Mon. XX., United States Geological Survey, 1892, pp. 308, 311, 316.

[2] "On the Origin and Classification of Ore Deposits," *School of Mines Quarterly*, 1910.

domorphs, and certain of them could be shown to have resulted, not from a solution of the first mineral and a refilling of the space with the secondary mineral but by a gradual molecular substitution of one substance for another. Lindgren[1] has cited the various proposed classifications of pseudomorphs, so that at this point they need not be repeated.

From its application in the case of a single mineral the process of molecular substitution was then applied by geologists and palæontologists to fossils composed of separate mineral grains. The pseudomorphism in this case was a retention of the form and internal structure of the fossil rather than of its individual crystalline grains, though the passage from a single crystal to an aggregate of crystals was simple and involved no new supposition. Archibald Geikie, writing in 1882, gave an admirable statement of the process as applied to fossils.[2]

The application of this process to ore-bodies did not, however, proceed as rapidly. Emmons has shown[3] that Charpentier distinctly formulated the theory of replacement as early as 1778, but, like many opinions expressed without evidence, it seems to have remained unnoticed for many years.

Pumpelly was the first to apply it in the United States to the copper deposits of Lake Superior in 1873.

In 1886 it was applied by Emmons to the ore-deposits of Leadville, Colorado.

In 1887–8 it was applied by R. D. Irving and Van Hise to the formation of the iron ores of the Lake Superior region in the Penokee Gogebic range.

In all these cases it was asserted that no open space had ever existed other than that necessary to permit waters to gain access to the rock affected; that ore-bodies grew in rocks through the gradual replacement of the material by the new substance taking its place. The interchange of material was supposed to have taken place by a chemical process, in a measure akin to the

[1] *T. A. I. M. E.*, Vol. XXX., pp. 581–584.

[2] "Text-book of Geology," 1st ed., 1882, p. 610.

[3] Emmons, S. F., "Theories of Ore-Deposition Historically Considered," *Eng. and Min. Jour.*, Vol. 77, p. 119.

replacement of one crystal by another with retention of the form of the original, known under the general name of *pseudomorphism*. The process of replacement was correlated with pseudomorphism only in a vague way, and was termed *replacement, substitution, metasomatism, metasomatic interchange,* etc.

The hypothesis once formulated, and illustrated by definitely recognized instances, gained ground rapidly, and up to 1900 was applied to the formation of many ore-deposits both in limestone and other rocks. Like nearly every explanation of natural phenomena not previously understood, origin by replacement has been eagerly ascribed to a vast number of deposits, some of which probably have had such an origin and some of which undoubtedly have not, as subsequent careful investigation has proved. The pendulum of thought indeed at one time swung so far to the side of replacement that some geologists questioned whether banded fissure veins might not have been formed entirely by this means.[1]

A more conservative attitude of mind has now followed, and the rôle of replacement as an ore-building process is applied with more care to only those ore-bodies which permit no simpler explanation.

Until 1900, no attempt was made to formulate definitely any correlation between metasomatic processes of ore-formation and pseudomorphism, or to present the subject in a connected paper dealing with the process in general. In that year, however, Mr. Waldemar Lindgren published a paper in the *Transactions of the American Institute of Mining Engineers,* entitled "Metasomatic Processes in Fissure Veins."[2] In this essay the chemical and physical nature of the processes involved in the alteration of vein-walls are discussed with such clearness and precision that economic geology owes to him for this masterly treatment a debt of gratitude which cannot be overestimated.

In many respects there is little to be added to what Mr. Lindgren has so clearly presented. But it must be remembered that

[1] Emmons, *Trans. Am. Inst. Min. Engs.,* Vol. XV., p. 123.
[2] *Tr. Am. Ins. Min. Engs.,* Vol. XXX., pp. 578–692.

his paper deals chiefly with fissure-veins, in which metasomatic processes have formed ore-bodies essentially subordinate in importance to the fillings of cavities through which the replacing solutions have circulated. He was also especially concerned with the mineral changes of vein-walls, that is, his paper was chiefly mineralogical and chemical. It is not the purpose of the writer to enter into such a detailed discussion of the chemical problems of replacement but rather to describe some of the characteristic features of replacement deposits and to attempt to establish some criteria by means of which the effects of the process may be recognized. He will also be concerned chiefly with those ore-deposits in which replacement has been the preponderant process and cavity-filling has been only subordinate. As such deposits are more common and larger in limestone formations than elsewhere, the paper will of course deal more largely with them than with other types.

Forms and Dimensions of Replacement Ore-bodies.

Ore masses formed by replacement are characterized by great variations in size and a bewildering variety of form. As they are independent of open space available for free deposition, the size which they may attain is subject to no definite limits. They range from narrow mineralized borders forming penumbral margins around the edges of filled rock-cavities, to huge masses which equal or exceed in their dimensions nearly all other types of ore-deposits. Those which are formed by the replacement of massive limestones especially are apt to attain great size, presumably on account of the facility with which the process goes on in this very soluble rock. Their great irregularity precludes exact estimates of volume, but the table below gives the approximate maximum dimensions of some well-known bodies of this kind.

The first impression gained from a comparative study of the collected plans and sections of replacement ore-bodies is that of great variety and extreme irregularity of form. The series of typical plans and sections from Leadville, Eureka, The Bo-

	Maximum Length, Feet.	Maximum Width, Feet.	Maximum Thickness, Feet.
Henriette—Wolftone—R. A. M. Shoot Leadville (ox. and sul.)	3,500	1,600	200
Moyer Main Shoot (sulphides) Leadville	2,340	1,300	150
Gold Ore Shoot (oxidized ore) Leadville	3,000	400	240
Greenback Shoot (sulphides) Leadville	500	350	300
Eureka Nevada[1]	400	150	100
Copper Queen Ore Bodies.			
I.	600	250	150
II.	600	830	100
III.	500	225	150

nanza, The Black Hills,[2] etc., shows the extremely intricate and complicated shapes which these masses frequently assume. A more careful study, however, both of these plates and of the actual occurrences in the field shows that nearly all these intricacies of form are referable to well-defined causes and are not fortuitous.

The shape of a replacement ore-mass is due:

1. To its relation to the channels of access of ore-bearing solutions;

2. To the variations in chemical character and structural arrangement of the enclosing rock;

3. To the manner in which mineralizing waters have affected the rock;

4. To the amount of material supplied in solution.

I. RELATION OF REPLACEMENT-BODIES TO CHANNELS OF ACCESS.

No substitution of ore for country-rock can occur, unless solutions have first been able to reach the rock susceptible to replacement.[3] Openings in rocks are of many differ-

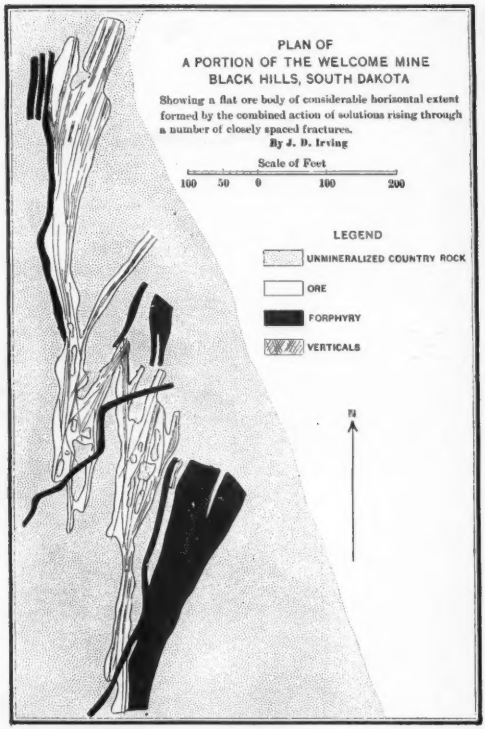
[1] The Eureka ore-bodies are so extremely irregular that any exact measurements are impossible. These dimensions are measured on the "800 ore body," Plate III., Mon. VII., U. S. Geol. Survey.

[2] Figs. 72, 74, 79, 68, Plate X.

[3] Exception is of course to be made in the case of contact metamorphic ore deposits when ore-bodies develop in the neighborhood of intrusive igneous masses which have themselves yielded the solutions for the mineralization of the adjacent rock. Such deposits may form without the pre-existence of channels.

ent kinds and it is, of course, possible for replacement to be initiated from any of them, irrespective of form or origin; joint cracks, fissures, large faults, brecciated zones, horizontal spaces between separated strata, vesicular cavities, intergranular spaces, etc., serve equally well as starting points for the process; but those which are comparatively small and are discontinuous have simply permitted the easy penetration and mineralization of a susceptible rock-mass, and cannot be regarded as the main channels of access. To serve as adits or connections between susceptible rock-masses and deeper seated sources of mineralizing waters, cavities must be continuous for considerable distances. They must be trunk channels of some kind. That a susceptible rock should be porous, open-textured, brecciated, jointed, etc., is an aid to mineralizers, once they have reached the rock affected, but it is insufficient in itself to afford access to them. Hence, replacement ore-bodies are generally associated with fissures of some kind which are either singly or collectively capable of conducting solutions from considerable distances to the locus of deposition. There are few if any instances with which the writer is familiar which do not permit either the actual observation of these fissures or their inference from the form and distribution of the ore-masses. In the siliceous gold-ore shoots of the Black Hills, South Dakota, they can be actually observed in the shale roof of the ore-bodies, sometimes as single fractures, sometimes as sheeted zones (see Plate X.), sometimes as broad zones of intersecting fracture. In Leadville they are observable in some cases extending downward from the ore-bodies into the granite underlying the susceptible rock series as fissure veins of considerable width, or they may be inferred from the regularity of trend of the shoots when plotted on a map (see Fig. 72, p. 541). The absence of fissures beneath many of the large ore-bodies of this region is probably due to the facility with which limestone rocks become recemented after rupture.

In the case of fissure-veins with limited amount of replacement along the walls the channel of access is so very much more


PLAN OF
A PORTION OF THE WELCOME MINE
BLACK HILLS, SOUTH DAKOTA
Showing a flat ore body of considerable horizontal extent formed by the combined action of solutions rising through a number of closely spaced fractures.
By J. D. Irving
Scale of Feet
100 50 0 100 200
LEGEND
UNMINERALIZED COUNTRY ROCK
ORE
FORPHYRY
VERTICALS
N

A FLAT BODY OF ORE PRODUCED BY THE REPLACEMENT OF A LIMESTONE BED SHOWING THE RELATION OF REPLACEMENT TO FISSURES.

(After Irving, U. S. Geological Survey, Professional Paper 26.)

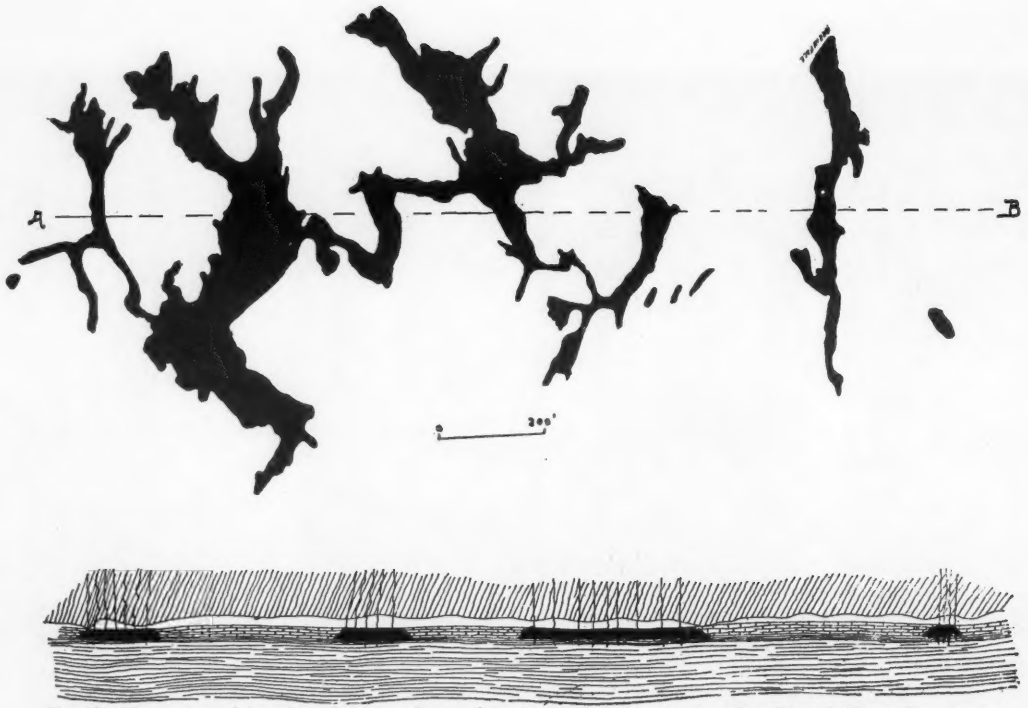


FIG. 68. Plan and partial section of the ore-shoots of the Penobscot mine, Garden City, Black Hills, S. D. Shows the relation of the form of the ore-bodies to "channels of access" and manner in which small offshoots form on single fractures which run out into the rock from the main fractured zones. From the published report of the company.

prominent than the replacement mass arising from it that there is no possibility of doubt as to the opening from which the mineralization started.

When solutions have once gained access to rocks susceptible to replacement, joint cracks, rock pores, brecciated structures, stock-works and other smaller and less continuous openings, by affording easy circulation and increasing the available surface for chemical action, greatly facilitate and accelerate the process.

Forms Due to Single Fissures.—Where replacement has proceeded from a single fissure *intersecting a homogeneous* rock the form of the resulting replacement mass is usually tabular. Its boundary is sometimes extremely indefinite, the new minerals becoming more and more sparsely scattered as one passes outward from the conduit which admitted the solutions until the ore passes insensibly into country rock. At other times it is extremely sharp, so that the passage from ore to country-rock is abrupt (see Fig. 69, A, B and C).

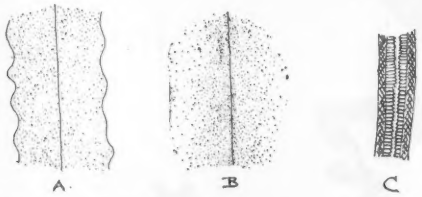


FIG. 69. Diagrammatic sketches. *A* shows how replacement which arises from a single fissure is sometimes sharply separated from the mineralized rock. *B*, the same relation to a fissure but fading gradually into the country. *C*, filled fissure with no replacement.

In all cases, however, the boundary, though as a whole tabular, is rarely parallel in detail to the wall of the channel of admission, and irregular arms extend outward from the main replacement-mass where solutions have for some reason operated more extensively than in other places. In some cases, as at East Huell

Lovell, Cornwall, England, the rock along some one portion of an opening has been more extensively attacked than at others. A lenticular mass is then produced (Fig. 70).

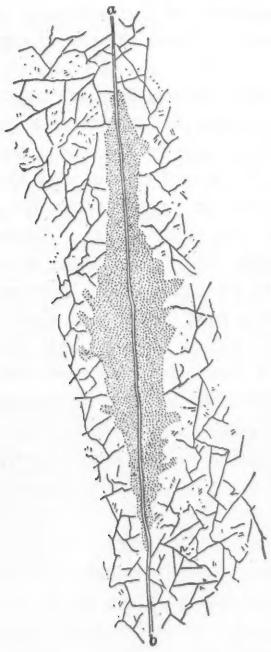


FIG. 70. (After Philips-Louis.) Horizontal section of "carbona" on the 100 ft. level of East Huell Lovell, Cornwall. Width at widest point, 9 ft. Shows how rock along one portion of channel of access is extensively replaced and elsewhere more slightly.

It is often difficult to determine, where fissures intersect homogeneous rock-masses, why some portions of the wall-rock have been extensively attacked and others scarcely at all; yet this is frequently the case. Possibly a slightly greater porosity, or

the absence of intervening layers of impermeable selvage-clay, or a slight difference in the composition of the original rock, may have determined it, or the constriction of the fissure above the most extensive replacement mass may have permitted the stoppage and stagnation of the solutions and afforded them more time in which to effect an interchange of new for old minerals.

In some cases such replacements are asymmetrical laterally; a selvage-clay on one side having prevented replacement so that the rock on the other only has been attacked.

The distance to which replacement may extend from a single channel varies greatly. In compact rocks like granite it is usually small, perhaps not over 4 or 5 feet. Again in the Cambrian limestone in the Black Hills, the distance is not very great, possibly not over 10 to 15 feet. In the more permeable limestone in the Neodesha mine near Ouray it extends for more than 100 feet. Such a great extent from a single fissure is exceptional, especially where the fissure is in homogeneous rock, all portions of which are equally susceptible to replacement.

When viewed in plan, shoots arising from single fissures are seen to have a roughly lenticular form, the widest portion being at that point where the supply of mineralizing water was present in greatest amount (see Fig. 70).

Forms Due to Multiple Fissuring.—If all fissures were widely separated single openings, it is probable that replacement masses would show little variety of form other than that which will be later described as due to the chemical composition and structural arrangement of the rocks intersected by the opening. Fissures are, however, notably variable in their position and relation to one another. They rarely occur alone, but rather in parallel or intersecting groups or systems. Where more than one fissure or opening occurs nearer to another than the distance to which replacement may proceed, the replacement mass arising from one fissure coalesces with that proceeding in the opposite direction from the fissure next adjoining; and a large mass of ore is thus produced.

It is then obvious that the larger features of the form of a replacement mass, that is, the form as a whole, in a homogeneous rock will be determined by the distribution and spacing of the openings. If viewed in section and plan, fissures may be arranged (1) in parallel groups, (2) in intersecting groups.

Parallel Groups. Lode Fissures.

Parallel fissures accompanied by extensive replacement give rise to what may be conveniently termed *lode fissures*.[1] Where rocks have been fissured and faulted, the movement, instead of being confined to a single fissure, is distributed along a series of parallel fissures, usually of very small width, which include between themselves narrow, tabular plates of country-rock. These fissures are generally closely spaced along the center of the zone, *i. e.*, the plane of maximum movement, but separated by wider and wider plates of country-rock in either direction. Such groups of parallel fissures are often termed "sheeted zones."

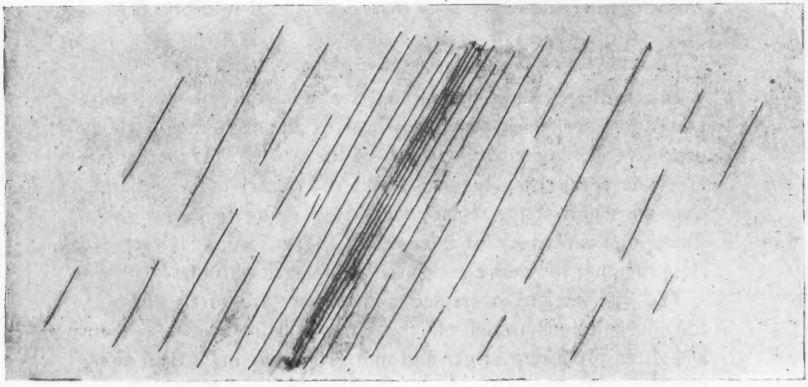


FIG. 71. Lode fissure formed by the replacement of plates of rock in between multitudes of parallel fractures. Fissures decrease in number from center of disturbance outward.

[1] These are termed by Emmons, *replacement veins*. See text accompanying Butte Special Folio, U. S. Geological Survey, Folio No. 38.

Solutions entering a sheeted zone replace the narrower plates completely but form only narrow margins of ore adjacent to those more widely separated. Fig. 71 above illustrates a fissure of this kind.

It thus happens that in lode fissures the central portion only is a solid mass of ore, beyond which the individual fractures are separated too widely to allow the mineralization arising from adjacent fissures to coalesce. The main lode is therefore separated by a plate or wall of barren rock from narrower parallel side lodes, and important and commercially valuable veins are not infrequently overlooked through a failure to understand the origin of the vein. Traces of the original fissures are generally observable in solid lode fissures and give rise to a banded structure which is often difficult to distinguish from crustification.

In horizontal projection lode-fissures differ little if at all from normal fissure veins, into which, indeed, they pass by imperceptible gradations when the open space increases in amount close together the entire rock mass is changed into ore.

Intersecting Groups.

Intersecting fissures divide rock masses into groups of polygonal, angular blocks and the form of the resulting ore-body depends chiefly upon the closeness of the spacing. If the fissures are wide apart the polygonal blocks of country-rock are larger than the width of the replacement body arising from any single fissure and a network of intersecting shoots results; if they are close together the entire rock mass is changed into ore.

The intersections of replacement shoots are rarely angular, for the solutions round off the narrow points between them and often produce a larger and more irregular mass than along that part of the fracture which is further removed from the point of intersection. The presence of stockwork-like fissures can, however, be readily detected in such masses at their edges, since the fractures there are fewer in number and run out into the unmineralized rock. The replacement shoots arising from them

also run out into the country, forming a peculiar fringe of little offshoots or apophyses which by their parallel arrangement disclose the presence of the fissure-systems which have given rise to them.

FIG. 72. Plan of ore shoots on Iron Hill, Leadville, Colo. (After A. A. Blow, *Am. Inst. of Min. Eng.*, Vol. 18, Plate I., opp. page 180. Corrections and additions made by the writer.) Shows great size of shoots, irregularity of outline in detail and evidence of formation along zones of fissuring. (North is toward the left in the map.)

As movements which result in the rupture of rocks generally occur along lines or linear zones whose longer diameter is very much greater than the distance across them, these masses are generally linear, *i. e.*, very much longer than they are broad.

In massive rocks, like heavy bedded limestones, the fracturing of the rock is often so irregular that the polygonal blocks which intervene between individual joints have very complicated forms

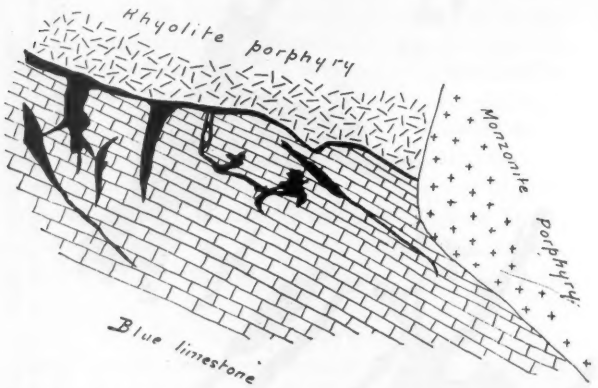


FIG. 73. Cross-section of the ore shoots of the Oro La Plata mine, Leadville, Colo.; showing the extremely irregular character of the ore shoots formed along irregular fractures in the Blue Limestone.

and the resulting ore masses are extraordinarily intricate. Figs. 73 and 74 will illustrate this.

When multiple intersecting systems of closely-spaced minute fissures intersect rocks which are chemically more resistant than limestone, as in the Treadwell mine in Alaska, the replacement extends to only very short distances from any single fissure and yet the resulting mass through which the ore is disseminated is of very great size.

Minor Irregularities of Outline.—In addition to the larger features of form which are more or less directly referable to the distribution and arrangement of fissures, there are many

FIG. 74. Horizontal and vertical projections of the Eureka, Nevada, ore-bodies showing result of large replacement masses formed along planes of intersecting fracture in heavy limestone. Scale of section one-half scale of plan. (The upper cut is after Curtis, Mon. VII., Plate III., U. S. Geol. Surv., the lower after Keyes, *Trans. Am. Inst. Min. Engs.*, Vol. VI., Plate VIII.)

detailed irregularities which are independent of the opening from which waters have operated. When solutions migrate outward from a fracture they replace the rock to varying distances. The resulting surfaces of demarcation between the outside edge of the ore mass and the unaltered country-rock are therefore rarely parallel in detail to the edge of the opening from which the solutions originated. While these surfaces are in some cases roughly parallel to the fissure and only irregular in their more minute details, in others the ore extends out in "pipes" or arms which wander without regularity of direction for considerable distances beyond the main body of the ore, and form a mass whose outlines are frequently bewilderingly complex. Between these two extremes all gradations occur.

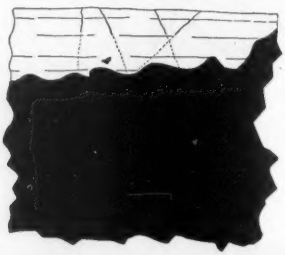


FIG. 75. Galena replacing limestone from Leadville, Colo., showing wavy line of demarcation between galena (black) and limestone (white). About one-half natural size.

Figs. 75, 76 and 77 will show irregularity in the detail of the lines of demarcation between ore and rock. In these specimens the boundaries are sharp and do not, as is often the case, fade off gradually into the surrounding rock.

In some cases long pipe-like arms, roughly circular in cross-section, wander outward, twisting and turning as they go for sometimes as much as 30 or 40 feet away from the main mass and apparently independent of any perceptible opening. One of these is shown in Fig. 78.

Apophyses of this kind are often difficult to explain. They

are probably due to differing porosity in the areas replaced; but no comparison can be made of the rock replaced with that unaffected, as it has all now been altered to ore. Care must be

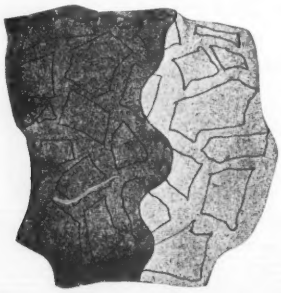


FIG. 76. Wavy line of demarcation between ore (dark) and limestone (light) from siliceous ore on Dacy Flat, Ragged Top, Black Hills, S. D. The general direction of the supplying fissure is about parallel to the right hand edge of the specimen. About one-fourth natural size. The rock is brecciated and the form of the fragments preserved in the ore.

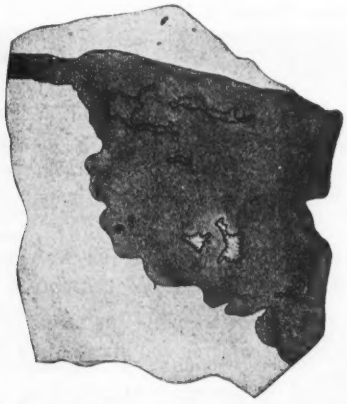


FIG. 77. Specimens of siliceous ore from Penobscot mine, Black Hills, S. D. Shows wavy line of demarcation between ore (dark) and limestone (light). About one-half natural size.

taken not to confuse irregular arms and apophyses of ore of this kind which are independent of any auxiliary fissure with "pipes" of ore such as those in the Yankee Boy and Guston mines[1] near Silverton, Colo. The latter seem to have been formed along what Schwartz terms "ore breaks," that is, channels of maximum permeability along intersections of sheeted zones or fissure-systems.

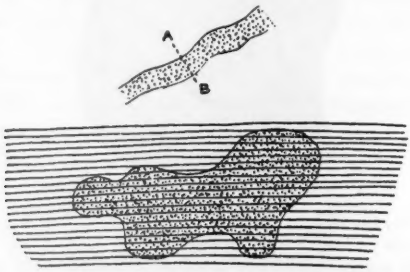


FIG. 78. Plan and cross-section of long irregular arm of ore which makes out from the main body into the stratified limestone and preserves the sedimentary banding of the limestone in the ore. Scale of section 10 times that of plan. Portland mine, Portland, S. D.

The apophyses here described are merely irregularities in detail of the free faces of masses which are in general easily referable to some fissure in the country rock and are rarely of large dimensions unless some auxiliary fissure or opening in the rock has determined their form and extent. Fig. 79 shows both classes of detail at the edges of a single ore body.

VARIATIONS IN CHEMICAL CHARACTER AND STRUCTURAL ARRANGEMENT OF ENCLOSING ROCKS.

Fully as important in determining the shape of replacement masses is the chemical character and structural arrangement of the enclosing rocks.

Fissures do not, of course, occur exclusively in homogeneous rocks, or in rocks composed of grains of one mineral only. They

[1] T. E. Schwartz, *T. A. I. M. E.*, Vol. 26, p. 1056.

frequently pass through rocks of widely varying lithologic character or rocks that, although as a whole homogeneous, are made up of aggregates of different minerals which have widely different susceptibilities to replacement processes.

Forms Produced in Rocks Composed of More than One Mineral.—When rocks are mechanical mixtures of different minerals,

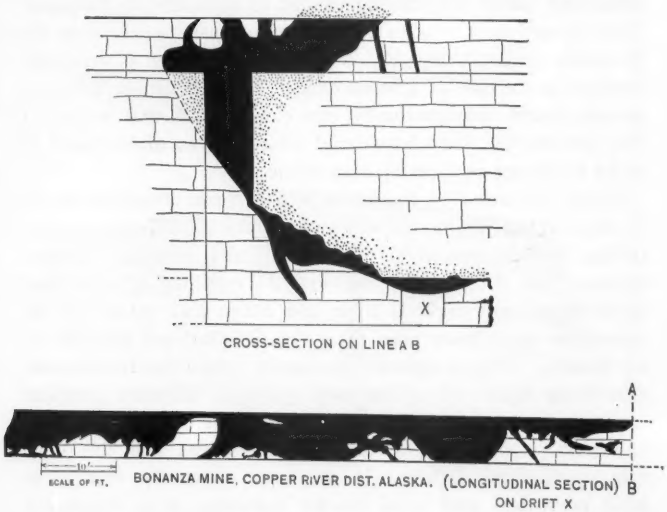


FIG. 79. Plan and section of tunnel and winze in Bonanza mine, Chitina River Copper District, Alaska. Shows a large body of almost solid chalcocite replacing limestone. The irregularity in detail and the partial relation of this irregularity to fissures is indicated very clearly in this section. Scale of both sections is the same.

some minerals will be more resistant to chemical alteration or replacement than others. Thus, in a calcareous sandstone composed of grains of sand cemented together by calcite, the calcite will be readily replaced, but the more resistant quartz left without alteration. In a granite composed of feldspars, muscovite and quartz, the feldspars may suffer replacement, and the quartz and mica remain unaffected. It therefore happens

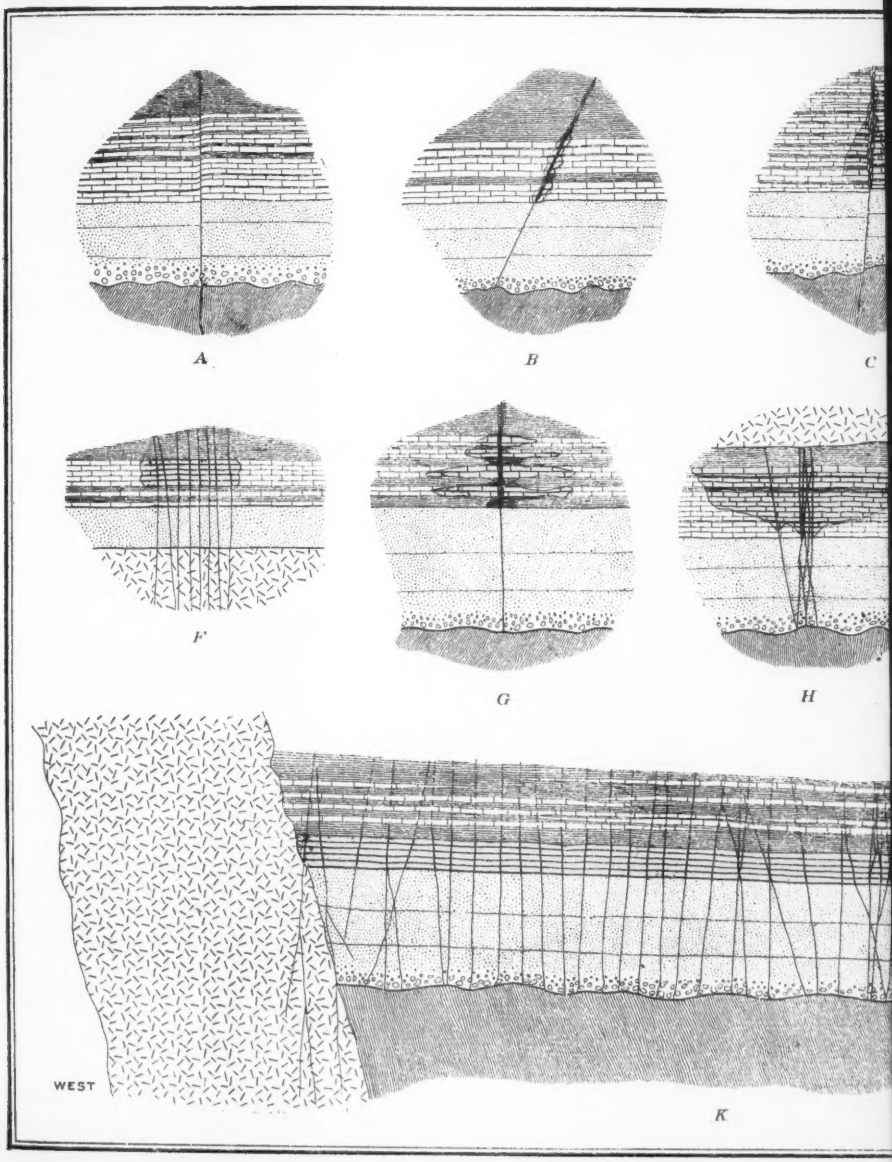
that rocks of this kind when affected by any given solution will often be but partially replaced, and the ore resulting from the process will be disseminated through the mass in much the same way as the original susceptible mineral.

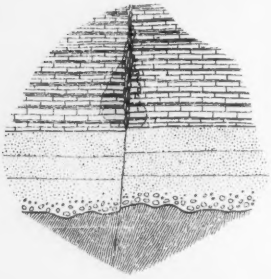
A calcareous quartzite of this kind has been transformed into ore in some of the silicious ore-districts in the Black Hills, the cementing calcite only having yielded to mineralizing processes. This disseminated type of replacement-deposit, where only the favorable minerals of the rock have been replaced is especially common in the case of igneous rocks. The edges of such masses almost always fade gradually into country-rock and seldom if ever present the sharp boundaries which are so often found in rocks which are replaceable as a whole.

Forms Produced by Variation in Structural Arrangement of Rocks.—When fissures pass through rocks of differing susceptibility, the more susceptible rocks are usually replaced to greater distance than the unsusceptible, and the resulting form is then tooth-shaped and depends upon the shape and extent of the susceptible layer more than upon the direction and position of the fissures. This is especially noticeable where fissures intersect alternating layers of sedimentary rocks of different chemical composition, such as limestones, shales and quartzites. The limestones will usually be extensively replaced and the other rock-layers only slightly. If only one especially susceptible layer is present and is of limited thickness, it is frequently replaced completely from underlying to overlying insoluble layer, and the result is a bedded deposit with irregular boundaries only where the end of the replacement mass crosses the replaced bed. Elsewhere it is evenly and often conformably bounded by the adjacent insoluble strata. In plan the forms of bedded masses such as this are determined by the fissures or fissured zones along which they extend. An excellent illustration is that given in Fig. 68 (see page 535) where the bedded form due to the position and thickness of the original limestone layer is admirably seen in cross section, and the irregular outlines and evidence of intersecting fissure-systems are seen in the plan.

PLATE XI.

PLATE XI.





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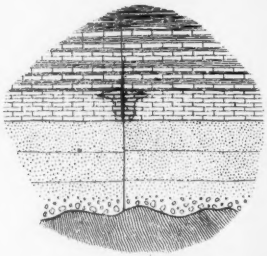

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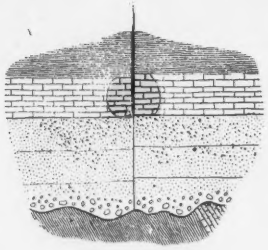

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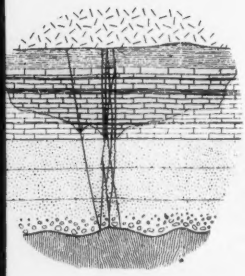
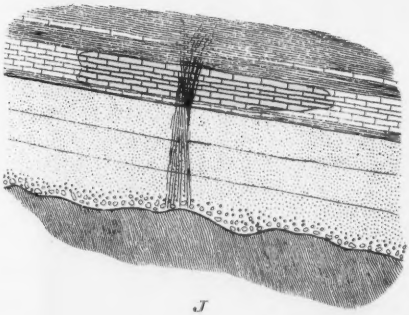


H

Shales and intercalated layers of impure dolomite

Sketch of mineralized fractures in Alameda mine near Portland showing replacement of main dolomite bed and partial replacement of impure layers of dolomitic shales

I



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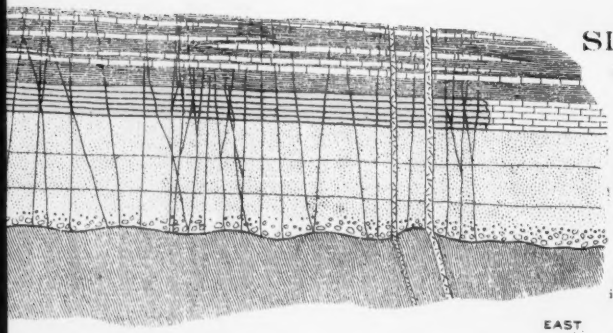

K

EAST

TYPE CROSS SECTIONS OF SILICEOUS ORE SHOOTS

Showing various forms taken by the mineralization as it proceeded outward from the supplying fissures

By J. D. Irving

Scale

25 0 25 50 feet

LEGEND

Comparatively impervious slate

Dolomite

Hard quartzite

Algonkian schists

Porphyry

Conglomerate

Ore (mineralized portions of the country rock)

E

ECTIONS

SHOOTS

the mineralization.
supplying fissures

g

20 50 feet

quartzite Algonkian schists

te Ore
(mineralized portions of the country rock)

Another illustration where the fissure is relatively wide and the replacement bed extends only for a short distance away from the fissure is shown in Fig. 80.

If the replacement mass is smaller than the susceptible rock mass which lies between the impervious bounding rocks there will be a line of demarcation between it and the unreplaced portion of the susceptible rock which will have the usual wavy outline or will show gradual transition into country rock." For the sake of convenience this may be called the "free face." Plate XI. and Fig. 81 shows plans and sections of the ore shoots from the Black Hills of South Dakota which illustrate this feature.

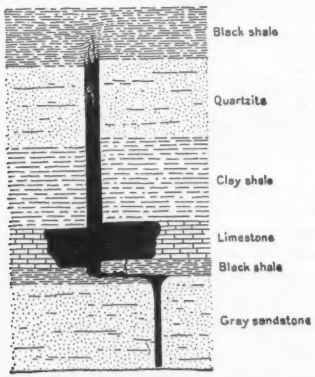

FIG. 80. Cross-section of Black Girl vein near Ouray, Colo. Shows a fairly wide fissure vein intercepting limestone beds with replacement shoot formed in the limestone and extending to 15 or 20 feet from the fissure on either side of the main vein. After Irving, Bull. 260, U. S. G. S.

It is easy to see why such masses as that shown in Plate XI., Fig. K, were confused by early writers with sedimentary layers and why they are still included by many writers among the "bedded deposits" where the old classification by form is still in use. It would be exceedingly interesting to learn whether the much discussed and oft cited Mansfeld copper shales do not in reality belong in this group of flat conformable replacement

deposits, which owe their form entirely to the position and chemical character of the replaced layer.

Sometimes a replaceable bed or mass of limestone is entirely enclosed in a relatively impervious porphyry, and the entire limestone body has been replaced. The resulting ore-bodies then have the form of the original limestone mass.

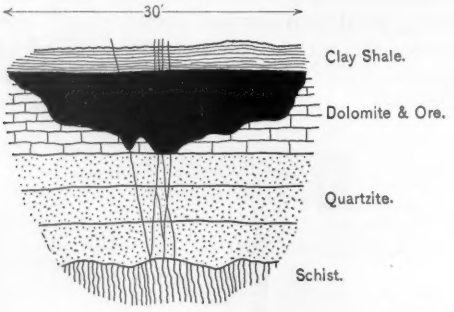

FIG. 81. Form of shoot influenced by rock structure. Spread of ascending solutions on under side of impervious shales has made shoot wide at top and with a characteristic pear-shaped form. Scale 25 ft., 1 in. Upper surface of ore is determined by adjacent impervious shales. The lower side is the "free face."

This was the case in some of the Fryer Hill ore bodies in Leadville (see Fig. 82).

As these were among the first ore bodies studied by Emmons in Leadville he was naturally confronted by what seemed to be an extremely difficult problem and it was only when he had seen the ore bodies in the incompletely replaced rock that their origin by replacement of limestone became clear.[1]

When more than one susceptible layer is present, *i. e.*, when susceptible strata alternate with resistant strata, the resultant ore body will finger out into the surrounding sediments or even retain the unsusceptible layers throughout the entire mass. Such ore bodies have, in cross section, saw-tooth forms or a sort of gridiron structure. An excellent illustration is given in Fig. 83.

[1] Oral communication.

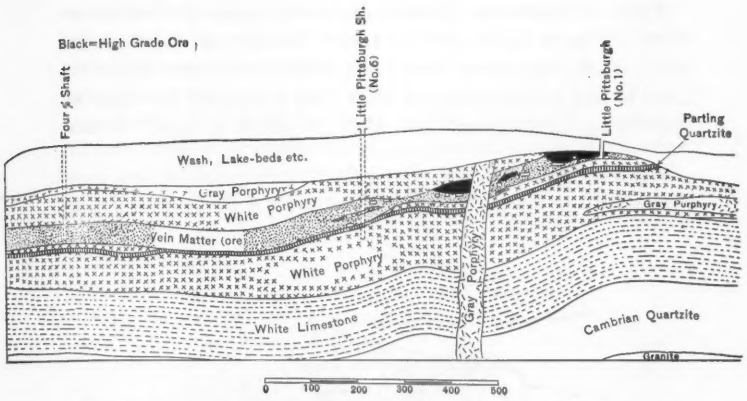

FIG. 82. Section of Fryer Hill, Leadville, Colo., showing how entire mass of limestone between two porphyry masses has been replaced and no limestone left. Form of ore-body determined entirely by bounding rock. There is no free face. (After S. F. Emmons, Mon. XII., U. S. Geol. Survey.)

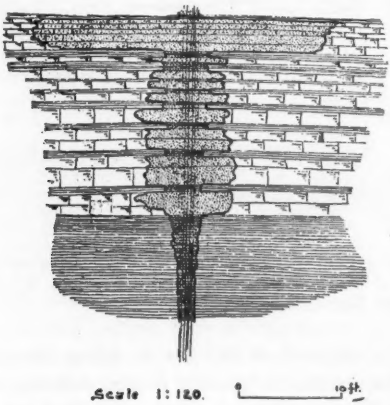

FIG. 83. Cross-section of ore shoot in alternating layers of shale and dolomite, Portland, S. D. The shales are only slightly replaced by silica but the ore in the limestone layers runs out to greater distances from the fissure.

Effect of Impervious Barriers and Constriction of Cavities on Form.—Waters which circulate rapidly through natural conduits produce less replacement than those which move more slowly or come to rest, probably because more time is afforded for reaction with the surrounding rock than when circulation is rapid. It thus

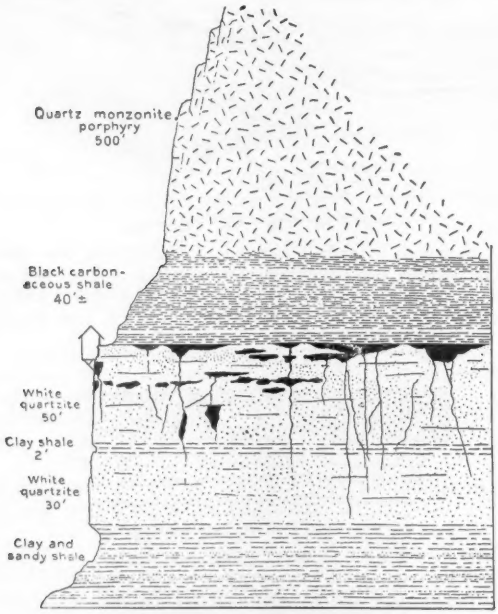

FIG. 84. Cross-section of the American Nettie mine, showing how pear-shaped shoots of ore have formed beneath impervious barriers of shale. (After U. S. Geol. Survey, Bull. 260.)

happens that if impervious barriers lie along the paths of fissures, or rocks occur in which the fissures become lost or constricted, the solutions will be dammed up, spread out beneath or upon the impervious rocks, and the mass replaced at the point of stagnation will be very much greater than elsewhere. When

waters are ascending (which is generally the case with primary ore-masses) this stagnation is greatest *beneath* an impervious rock, shale, eruptive rock, etc., or *beneath* a rock which has fractured less readily, and in which the fissures are comparatively constricted. The result is a large tabular mass roughly horizontal and with its greatest extent immediately below the barrier rock, and perfectly conformable to it, but with a lower surface or *free face* which is extremely jagged and with long tongue-like

FIG. 85. Plan of the workings of the American Nettie mine, near Ouray, Colo. The drifts follow the lines of fissure as shown in the section in Fig. 84. The mine workings thus bring out clearly the fissure systems.

apophyses running down into the soluble rock along the supplying fissures and fractures and finally dying out along them. Along a single fissure such deposits will often have a pear-shaped form in cross-section, such as that shown in Figs. 81 and 84. The impervious barrier in Fig. 84 is either a heavy black shale or a thinner interbedded layer of clay shale and the replaced rock a quartzite. The fissures are shown in plan in Fig. 85. In this instance there are in addition to the replacement masses in the quartzite numbers of filled solution cavities and the ore-

masses themselves are usually surrounded by solution cavities which show all of the concave surfaces and other criteria so characteristic of openings formed by solution. The main ore-masses, however, seem to have been formed by replacement.

Impervious barriers are effective in stagnating solutions not only when above or below the path of a fissure but also when they intersect it in a horizontal direction and even if parallel to the zone of fracturing. Thus in the Mineral Farm mine, a portion of which is shown in Fig. 86, a sheet of phonolite is

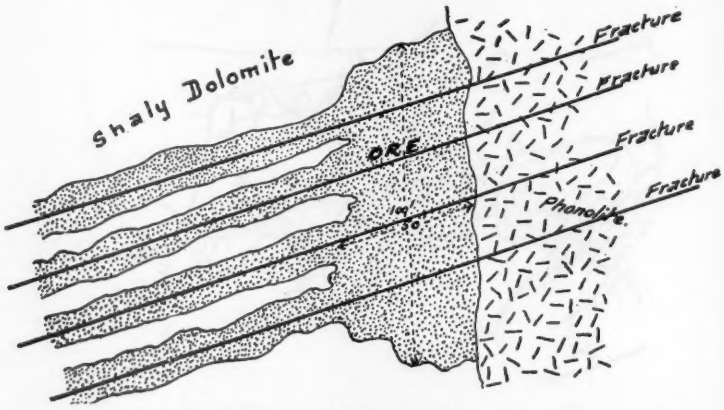

FIG. 86. Sketch plan of the Mineral Farm ore-body near Portland, S. D., showing how replacement of the country rock by silica has proceeded outward from the fractures but has only completely replaced the intervening rock when the porphyry barrier has dammed up the mineralizing waters.

intersected by a set of fractures which pass into it from the surrounding shaly limestone. The ore has completely replaced the rock adjacent to the phonolite; but has not connected the fissures at a distance of 50 feet from it. In the phonolite itself only a slight alteration, a fraction of an inch from the wall, has been produced.

In the case of the Tornado Mogul shoot, the largest body of refractory silicious ore in the Black Hills region, the ore-body

is bounded on one side by a dike of phonolite which has served to assist in the general stagnation of the solutions, and has resulted in the production of a very large body of ore. The same stagnation has been produced in the Elkhorn mine in Montana, as described by Weed, where solutions have risen and produced bodies of ore under anticlinal domes of impervious rock.[1]

It is to be remembered that in all cases where fissures or openings transect different types of rock the ore will (unless the mass of replaceable rock is very small) have some *free face,* from which the nature of the process may be inferred, and which will show the usual sharp wavy contour or gradual transition to rock characteristic of replacement ore-deposits.

Stagnation of solutions and consequent increase in the lateral extent of an ore-body need not, of course, be determined by an impervious barrier. The constriction of openings which decrease the rapidity of flow can occur within a single homogeneous rock-mass, and will cause the solutions to spread laterally and produce the wandering forms shown in many of the Leadville ore bodies.

This will also account for the occurrence of not a few bodies of ore wholly enclosed in limestone in the Leadville district. Most of the ores occur directly *beneath* the impervious capping; but some of them occur wholly within the limestone and in these cases it is presumable that the solutions never reached the impervious barrier.

EFFECT OF MANNER OF OPERATION OF SOLUTIONS ON ROCK.

If the replacement starts from a fissure in a homogeneous rock-mass, it may be conceived to operate in one of two ways.

1. The solutions may have first penetrated the rock along minute pores until they have saturated it for some distance from the fissure, the limit being set by the balance between the friction of diffusion and the difficulty of escape elsewhere. The solution may then operate from an innumerable number of separate centers (those farther away being fewer in number). As these

[1] Weed, U. S. Geol. Survey, 22d Ann. Rep., Pt. II., pp. 492 to 495.

separate small masses grow, they gradually interfere until coalescence unites them into one continuous body. At the edges of the body the centers of growth are more widely separated and the resulting masses are disunited, so that one may pass outward through first a solid mass of ore then through thickly disseminated particles of ore, then sparsely disseminated particles, and finally into country-rock entirely beyond the zone of alteration. It is obvious that this process of replacement may be arrested at any stage, either through lack of further supply of solution or through the final neutralization of all the chemically active agents in the circulating waters. If the process is arrested early the replacement will be incomplete, and will have the form of a mineralized zone throughout which little particles (often perfectly formed crystals) are abundantly scattered but nowhere united into an integral mass. Such replacement is often spoken of as disseminated replacement; an instance is described by Lindgren from specimens of silicified limestone from Aspen. See Figs. 87, 88 below. Replacement as seen in Fig. 87 has started at a number of separate centers. Then later the perfect crystals so formed have been surrounded by more replacement-quartz until the whole mass is replaced as in Fig. 88. The hexagonal outlines of the earlier formed crystals are still to be seen in the ore and have been, so to speak, the advance agents of the process.

Pyrite cubes embedded in later pyrite are common in Leadville ores and illustrate the same feature.

2. The second manner of operation is quite different and is typically illustrated by the Black Hills siliceous gold-ores. Here again taking a single fissure or channel of access as the easiset method of illustration, the outer boundaries of the ore are abrupt and all rock from the fissure to the final limit of mineralization is completely replaced. In not one of the great multitude of ore-bodies studied by the writer in this region, was a gradual transition from ore to rock observed. The boundary is often so sharp that no scale is so small that one division of it will not rest on ore and one on country-rock. Even in the smallest masses the abrupt transition is observable.

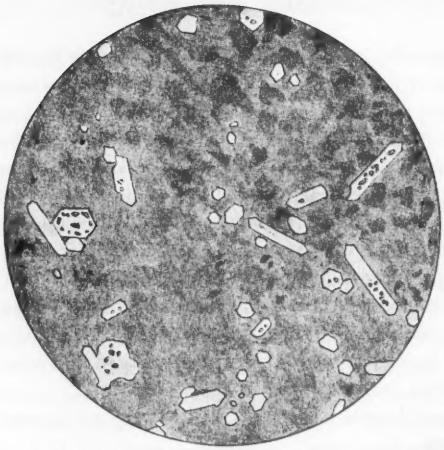

FIG. 87. Incipient silicification of limestone, Aspen, Colo. White areas represent quartz crystals with small inclusions of limestone. Magnified 30 diameters. (After Lindgren, *T. A. I. M. E.*, Vol. XXX., p. 628.) This is the nature of partly replaced rock where the process has been arrested before it was complete.

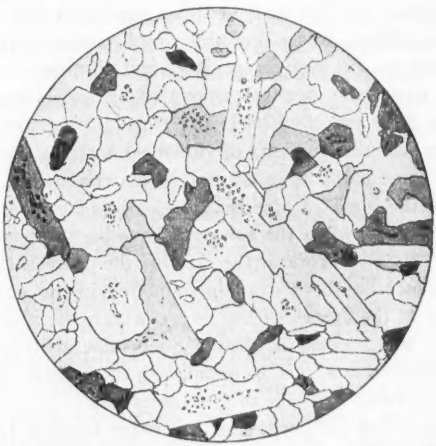

FIG. 88. Silicified limestone ("Jasperoid") Aspen, Colo. Crossed Nicols. All quartz. Small inclusions of calcite in some of the grains. Magnified 30 diameters. (After Lindgren, *T. A. I. M. E.*, Vol. XXX., p. 628.) This shows the process completed. Complete outlines of earlier formed automorphic crystals are seen in the later replacement silica which is xenomorphic.

In cases of this kind the rock adjacent to the fissure must first have been replaced, then that farther away and so on until when the process was arrested the boundary was left sharp, however far the alteration may have proceeded. In other words, the replacement has advanced like a wave over the country-rock until its termination has arrested it at some point. If the process has operated in this way the advancing solutions must have found their way constantly through the newly formed ore and as this is generally quite porous, due to the innumerable little cavities left by the decrease in volume, it has probably gained access to the outer wall in this way. These volume vuggs often contain crustified linings of minerals which have been deposited from the ore solutions, such as quartz and fluorite.

Where replacement proceeds in this way no disseminated ore is produced.

Whichever of these two ways has been the manner of operation the process has involved two distinct results, the introduction of the new mineral and the removal of the old. The latter might be termed the disposal of refuse. The dissolved rock has needed to find its way out just as the old has needed to find its way in.

It is not difficult to see how this could have occurred, because it is evident that the high temperature and dilution of ore-bearing solutions must have been accompanied by a division into ions which can have travelled back and forth through the solutions during the process, the ions of dissolved material moving back along the same paths as those of new material which were proceeding in the opposite direction.

In some cases, when the solutions have been apparently saturated with dissolved rock at the close of the process, the original rock substance has been again precipitated in the volume cavities, filling in the spaces of the vuggs within the minute crustified linings which occur in them. Such minerals might well be termed *renascent minerals,* to distinguish them from the *juvenile* minerals deposited from the original solutions.

It is aside from the purpose of this paper to enter further into the questions of physical chemistry involved in the process, for they are difficult and complex and only to be inferred from

geological evidence; but these suggestions may serve to stimulate experimental work along these lines.

THE AMOUNT OF MATERIAL SUPPLIED IN SOLUTION.

If the supply of mineralizing water is great and its introduction extends over a long period of time, the replacement will, of course, extend much farther from the channel of access than if it is very slight. This is well illustrated in the (Plate XI.) comparative series of cross sections of ore shoots in the Black Hills.

Ore shoots frequently terminate along their strike although the fracture or opening may continue, and is sometimes as large as that where the ore body is extensive. The supply of solution seems to have been confined chiefly to certain areas and its amount has been insufficient to produce extensive replacement except in the heart of the channels of flow. Cross sections A, B, E and J, show progressively decreasing amounts of mineralization from single fractures.

When all the causes which influence the form of a replacement ore body are together present in a single ore body, viz., form and distribution of channels of access, varying porosity, varying susceptibility, varying structural arrangement and varying supply of mine-waters, it is often difficult to determine which has exerted the maximum effect; but it rarely happens that some portion of an ore body cannot be found where each has alone been the determining factor.

Rocks Affected by Replacement.

Although this paper does not aim at a discussion of the chemical side of replacement processes a few words as to the susceptibility of the main rock groups are necessary.

It has been clearly shown by previous writers, notably Lindgren, that replacement may occur not only in calcite, dolomite, and other readily soluble minerals, but in a great variety of other more insoluble minerals, a few only escaping, even quartz suffering oftentimes at the hands of calcite, siderite and minerals ordinarily considered quite soluble. It therefore follows that rocks

made up of aggregates of these minerals will suffer replacement.

As different minerals are differently affected by solutions, rocks will be more or less completely replaced according as they are made up of aggregates of the same or of different minerals. Pure or fairly pure limestones, being composed of aggregates of calcite or dolomite grains with comparatively little other material, and that scattered widely through the rock, are far more extensively and completely replaced than any other type of rock. The disseminated types of replacement-bodies in them are therefore relatively rare. As alumina and silica increase, they are the receptacles for less and less pure ore-masses, the alumina and silica often persisting unaltered in the ore resulting from replacement. Shale bands, rounded detrital quartz grains, etc., therefore remain unaffected and often constitute valuable criteria for the recognition of the process. Sandstones and quartzites are far less *extensively* affected, though they are perhaps as *often* replaced as limestone. Deposits in them, owing to their greater porosity, are apt to be disseminated and incomplete, starting as they do from innumerable centers at the same time and proceeding only slowly and with difficulty in so resistant a mineral. In the calcareous sandstones where the cement is calcite the calcite is often replaced and the detrital grains of quartz are left unaltered. In such replacements it is frequently a matter of extreme difficulty to distinguish between impregnations or the filling of intergranular spaces, and the actual replacement of the component grains of the original rock.

The least easily attacked rocks among the sediments are those containing high percentages of alumina. Such are the clay shales and the metamorphic derivatives. Those containing high percentages of alumina suffer least and will often persist without alteration in replaced limestones. Shales with high percentages of lime are often very extensively replaced.

With the igneous rocks, which are essentially heterogeneous, the conditions are usually different. They are aggregates of different minerals which are very differently affected by any given solution. For this reason igneous rocks are rarely wholly re-

placed, and deposits formed in them are generally disseminated or scattered, that is, solutions here exercised a selective effect, replacing some minerals and leaving others untouched or affecting them in a different way. Futhermore, the pore-space for the access of solutions is extremely small, as will be shown later. Instances of this type of replacement are Ely, Nev., the porphyry coppers of Bingham, Utah, and other similar occurrences.

(*To be concluded.*)

A PLEA FOR REVISION OF THE RULES OF THE AMERICAN CHEMICAL SOCIETY GOVERNING THE PROXIMATE ANALYSIS OF COAL.[1]

MARIUS R. CAMPBELL.

The recent publication, by the West Virginia Geological Survey,[2] of all analyses of coals of that state that have been made in recent years, affords an opportunity for the comparison of results obtained by different chemists in different laboratories. Such a comparison shows clearly that, although these laboratories may be well equipped and the chemists follow closely the rules laid down by the American Chemical Society for making proximate analyses, the results are very discordant and can not be relied upon for determining the comparative values of coals or for their classification. Heretofore the demands have not been such as to require great accuracy in coal analysis, but with the constantly and rapidly growing practice of buying coal on specifications and the need for a scientific classification of at least the high grade coals, accuracy and uniformity of results become of the utmost importance. The object of this paper is to call attention to these discordant results and to urge that the American Chemical Society revise its regulations, introducing such refinements that it will be possible for any chemist to duplicate, within a reasonable limit of error the work of any other chemist, even though working in a different laboratory.

The West Virginia report in question contains not only all analyses made by the state, corrected and brought up to date, but also 140 analyses of Pocahontas and New River coals made at the Pittsburg laboratory of the United States Geological Survey. The former are analyses of individual samples, but the latter were made of composite samples and really represent the average of about 500 analyses.

[1] Published by permission of Director of the U. S. Geological Survey.

[2] Levels and coal analyses: Bull. W. Va. Geol. Survey No. 2, 1910.

In comparing these analyses it must be remembered that they were not made on check samples, but merely on samples obtained in the same mine but by different collectors and in different years. Some may urge that uniformity of results is not to be expected from samples collected in such a way, but in the present case the striking feature is not the irregularity of the results, but the almost phenomenal regularity of the fixed carbon of the West Virginia analyses below those made by the United States Geological Survey.

Differences of this kind in such a large series of analyses effectually rule out the personal equation of the sampler, difference in method of sampling and differences resulting from samples being taken in different parts of the mine or coal bed, for errors of this kind would be variable—sometimes one way and sometimes another.

The discrepancies in the results, therefore, must be due to differences in laboratory equipment and methods of work. Recently it was found that the results obtained in the Pittsburg and Washington laboratories of the United States Geological Survey were not in accord and close investigation showed that the difference was due to the fuels used in these laboratories, Pittsburg using natural gas and Washington using artificial gas. In the present case fuel does not seem to enter into the question, as natural gas was used in both laboratories. The writer has been assured by Dr. I. C. White, state geologist of West Virginia, that his chemist followed exactly the rules laid down by the American Chemical Society, and the same rules have been observed by the chemists of the United States Geological Survey. Therefore, the discrepancies in the results are unexplainable at the present time, but doubtless they will be found to be due to some slight variation in practice or equipment, which apparently does not conflict with the regulations but which leads to very different results.

The following table shows the results obtained in the two laboratories on samples from 57 mines in the Pocahontas and New River districts, grouped according to coal beds. In order to

TABLE I.

SHOWING COMPARATIVE RESULTS OF ANALYSES MADE BY THE UNITED STATES GEOLOGICAL SURVEY AND THE WEST VIRGINIA GEOLOGICAL SURVEY.

Name of Mine.	Coal Bed.	U. S. Geological Survey, Pittsburg Laboratory.			W. Va. Geological Survey.			Excess U. S. G. S. over W. Va. G. S.	
		Fixed Carbon.	Volatile Matter.	F. C. / V. M.	Fixed Carbon.	Volatile Matter.	F. C. / V. M.	Fixed Carbon.	F. C. / V. M.
Jed	Pocahontas No. 3	87.4	12.6	6.9	84.9	15.1	5.6	2.5	1.3
Empire	" "	86.0	14.0	6.1	82.2	17.8	4.6	3.8	1.5
Hiawatha	" "	85.8	14.2	6.0	83.0	17.0	4.9	2.8	1.1
Lick Branch	" "	85.8	14.2	6.0	81.8	18.2	4.5	4.0	1.5
Upland	" "	85.7	14.3	6.0	81.0	19.0	4.3	4.7	1.7
Wenonah	" "	85.7	14.3	6.0	84.0	16.0	5.2	1.7	.8
Bottom Creek	" "	85.7	14.3	6.0	82.0	18.0	4.6	3.7	1.4
Shawnee	" "	85.6	14.4	5.9	81.7	18.3	4.5	3.9	1.4
Indian Ridge	" "	85.6	14.4	5.9	81.5	18.5	4.4	4.1	1.5
Keystone	" "	85.6	14.4	5.9	82.3	17.7	4.6	3.3	1.3
Elk Ridge	" "	85.6	14.4	5.9	83.5	16.5	5.1	2.1	.8
Buckeye	" "	85.4	14.6	5.9	81.8	18.2	4.5	3.6	1.4
Roanoke	" "	85.3	14.7	5.8	81.5	18.5	4.4	3.8	1.4
Pulaski	" "	85.2	14.8	5.8	82.6	17.4	4.8	2.6	1.0
Arlington	" "	85.2	14.8	5.8	82.0	18.0	4.6	3.2	1.2
Peerless	" "	85.2	14.8	5.8	82.4	17.6	4.7	2.8	1.1
Shamokin	" "	84.9	15.1	5.6	82.2	17.8	4.6	2.7	1.0
Louisville	" "	84.8	15.2	5.5	80.2	19.8	4.0	4.6	1.5
Lynchburg	" "	84.7	15.3	5.5	83.0	17.0	4.9	1.7	.6
Powhatan	" "	84.7	15.3	5.5	83.4	16.6	5.0	1.3	.5
Ashland	" "	84.6	15.4	5.5	80.7	19.3	4.2	3 9	1.3
Eureka	" "	84.6	15.4	5.5	82.1	17.9	4.6	2.5	.9
Turkey Gap	" "	84.4	15.6	5.4	82.9	17.1	4.8	1.5	.6
West Pocahontas	" "	84.4	15.6	5.4	79.6	20.4	3.9	4.8	1.5
Angle	" "	84.3	15.7	5.4	80.1	19.9	4.0	4 2	1.4
Coaldale	" "	84.2	15.8	5.3	80.7	19.3	4.2	3.5	1.1
Delta	" "	84.2	15.8	5.3	82.9	17.1	4.8	1.3	5
McDowell	" "	83.7	16.3	5.1	82.1	17.9	4.6	1.6	.5
Goodwill	" "	83.2	16.8	4.9	82.2	17.8	4.6	1.0	.3
North Side	" No. 4	85.7	14.3	6.0	83.0	17.0	4.9	2.7	1.1
Slab Fork	Beckley	85.7	14.3	6.0	82.9	17.1	4.8	2.8	1.2
Raleigh No. 3	"	84.2	15.8	5.3	83.3	16.7	5.0	.9	.3
Piney No. 4	"	83.5	16.5	5.1	82.6	17.4	4.8	.9	.3
Piney No. 2	"	81.6	18.4	4.5	80.6	19.4	4.2	1.0	.3
Laurel Creek	Quinnimont	83.2	16.8	5.0	81.0	19.0	4.3	2.2	.7
Beechwood	"	81.1	18.9	4.3	78.8	21.2	3.7	2.3	.6
J. B. & B. No. 2	Sewell	83.4	16.6	5.0	80.2	19.8	4.1	3.2	.9
Tamroy	"	82.5	17.5	4.7	80.4	19.6	4.1	2.1	.6
Lanark No. 3	"	82.2	17.8	4.6	79.0	21.0	3.8	3.2	.8
Sprague	"	82.1	17.9	4.6	80.9	19.1	4.2	1.2	.4
Raleigh No. 5	"	81.7	18.3	4.5	81.3	18.7	4.3	.4	.2
Prosperity	"	81.5	18.5	4.4	81.5	18.5	4.4	0.0	0.0
Derryhale	"	81.4	18.6	4.4	76.6	23.4	3.3	4.8	1.1
Price Hill	"	80.7	19.3	4.2	78.9	21.1	3.7	1.8	.5
Oswald	"	80.4	19.6	4.1	79.4	20.6	3.8	1.0	.3
Wingrove	"	80.4	19.6	4.1	81.1	18.9	4.3	— .7	— .2

Name of Mine.	Coal Bed.	U. S. Geological Survey, Pittsburg Laboratory.			W. Va. Geological Survey.			Excess U. S. G. S. over W. Va. G. S.	
		Fixed Carbon.	Volatile Matter.	F. C. / V. M.	Fixed Carbon.	Volatile Matter.	F. C. / V. M.	Fixed Carbon.	F. C. / V. M.
Sugar Creek.....	Sewell.....	80.3	19.7	4.1	79.2	20.8	3.8	1.1	.3
Sun.....	"	80.3	19.7	4.1	78.7	21.3	3.7	1.6	.4
Star.....	"	79.9	20.1	4.0	78.0	22.0	3.5	1.9	.5
Sherwood	"	79.9	20.1	4.0	80.4	19.6	4.1	— .5	— .1
Turkey Knob,.....	"	79.6	20.4	3.9	77.8	22.2	3.5	1.8	.4
Prudence	"	79.1	20.9	3.8	77.7	22.3	3.5	1.4	.3
Harvey.....	"	78.4	21.6	3.6	76.4	23.6	3.2	2.0	.4
Keeneys Creek.....	"	77.5	22.5	3.4	73.7	26.3	2.8	3.8	.6
Parral.....	"	77.5	22.5	3.4	76.2	23.8	3.2	1.3	.2
Stuart	"	77.1	22.9	3.4	77.7	22.3	3.5	— .6	— .1
Smokeless...	"	76.1	23.9	3.2	72.3	27.7	2.6	3.8	.6
Averages for Pocahontas No. 3.....		85.1	14.9	5.7	82.1	17.9	4.6	3.0	1.1
" " Beckley		83.8	16.2	5.2	82.4	17.6	4.7	1.4	.5
" " Quinnimount..		82.2	17.8	4.6	79.9	20.1	4.0	2.3	.6
" " Sewell.....		80.1	19.9.	4.1	78.4	21.6	3.7	1.7	.4

facilitate comparisons the writer has recalculated all of the analyses to the moisture-and-ash-free basis, thus showing the actual composition of the coal substance as well as a proximate analysis can show it. Also, he has given the fuel ratio (fixed carbon divided by the volatile matter), as most American classifications of the high grade coals are based on this ratio.

From this table it will be seen that in every case, except four, the fixed carbon in the Pittsburg analysis exceeds that of the Morgantown analysis, and consequently the fuel ratios of the former exceed those of the latter. The average excess of fixed carbon for 29 analyses of Pocahontas No. 3 coal is 3.0 per cent., and the average excess of fuel ratios for the same analyses is 1.1. The same averages for the four analyses of Beckley coal are 1.4 per cent. and .5, and for Quinnimont (Fire Creek) coal 2.3 per cent. and .6. In the case of the Sewell coal the work of the two laboratories is more accordant, but even here in 17 analyses the fixed carbon of the Pittsburg analyses is higher than in those made at Morgantown, three show the excess on the opposite side, and in one the same results were obtained in both laboratories. The average excess of fixed carbon for the whole number of

analyses of this coal is 1.7 per cent. and the average excess for the fuel ratio is .3. The average excess for the entire list of 57 analyses is 2.6 per cent. for the fixed carbon and .7 for the fuel ratio.

Similar comparisons may be made of analyses from the various laroratories of the United States Geological Survey and the Morgantown laboratory of the West Virginia Geological Survey as shown by the following table:

TABLE II.

SHOWING COMPARATIVE RESULTS OF ANALYSES MADE IN VARIOUS LABORATORIES.

Name of Mine.	1. U. S. G. S. Pittsburg Lab.			2. U. S. G. S. Jamestown Lab.			3. W. Va. G. S. Morgantown Lab.			4. U. S. G. S. St. Louis Lab.		
	Fixed Carbon.	Volatile Matter.	F. C. V. M.	Fixed Carbon.	Volatile Matter.	F. C. V. M.	Fixed Carbon.	Volatile Matter.	F. C. V. M.	Fixed Carbon.	Volatile Matter.	F. C. V. M.
Rush Run	79.5	20.5	3.9	79.6	20.4	3.9				76.1	23.9	3.2
Hemlock Hollow	83.7	16.3	5.1	81.3	18.7	4.3						
Piney No. 1	82.3	17.7	4.6	81.7	18.3	4.5						
Raleigh No. 1	84.5	15.5	5.5	82.8	17.2	4.8						
Sun	80.3	19.7	4.1				78.7	21.3	3.7	77.4	22.6	3.4
McDonald							77.8	22.2	3.5	76.7	23.3	3.3
Brooklyn				76.5	23.5	3.3	74.5	25.5	2.9			
Star	79.9	20.1	4.0	79.2	20.8	3.8	78.0	22.0	3.5			
Derryhale	81.4	18.6	4.4	80.1	19.9	4.0	76.6	23.4	3.3			
Smokeless	76.1	23.9	3.2	74.5	25.5	2.9	72.3	27.7	2.6			
Zenith	84.2	15.8	5.3							80.4	19.6	4.1
Turkey Gap	84.4	15.6	5.4	83.0	17.0	4.9	82.9	17.1	4.8			
Lick Branch	85.8	14.2	6.0	82.7	17.3	4.8	81.8	18.2	4.5			
Average excess of analyses 1 above analyses 2	1.4	—1.4	.5									
Average excess of analyses 2 above analyses 3	1.5	—1.5	.3									
Average excess of analyses 3 above analyses 4	1.2	—1.2	.3									

In this instance the number of cases is less, but the figures given in the table, with the exception of those from West Virginia, are the averages of from three to ten analyses. Inspection of the table shows that the highest fixed carbon was obtained in the Pittsburg laboratory, the second highest in the Jamestown laboratory, the third highest in the Morgantown laboratory, and the lowest at St. Louis. The difference between the average for the various columns 1, 2, 3 and 4 is remarkably regular, ranging,

as given in the table, from 1.2 to 1.5, but in making this comparison only those coals common to the columns being considered have been taken into account. When, however, the other analyses are compared a similar difference will be found to exist. Thus, in the Rush Run analyses the difference between column 2 and column 4 is 3.5, whereas the average difference between these columns is 2.7; in the Sun analyses the actual difference between columns 1 and 3 is 1.6 and the average is 2.9; and in the Zenith analyses the actual difference is 4.1 and the average 3.8.

The figures given in Tables I. and II., while not thoroughly conclusive, seem to indicate clearly that each laboratory has a different equipment or that each laboratory staff interprets the rules of the American Chemical Society in a slightly different manner from that of another laboratory. The conclusion seems to be clear that the American Chemical Society should frame such a set of rules and regulations that differences like the above would be impossible and the work of any high grade laboratory could be compared directly and confidently with that of any similar laboratory in the country.

COPPER, SILVER, LEAD, VANADIUM, AND URANIUM ORES IN SANDSTONE AND SHALE.

WALDEMAR LINDGREN.

General Characteristics.—In widely separated parts of the world and generally far away from igneous rocks ores of copper, lead, vanadium and uranium appear in extensive series of sandstone and shale under circumstances which indicate a common mode of origin. They are usually of low tenor and in the majority of cases can not be utilized. The primary ores are chalcocite, with small amounts of bornite, chalcopyrite and pyrite; galena; roscoelite, a vanadium mica; carnotite, a vanadate of uranium. Small amounts of nickel, cobalt, molybdenum, barium, and selenium are often found. While all these sometimes occur together, they are more commonly segregated into separate deposits in which one metal predominates. Gangue minerals are conspicuously absent or confined to a little calcite, barite, and gypsum, the latter probably secondary. Where exposed to the atmosphere oxidized minerals develop.

The deposits are rather conspicuously confined to certain formations or members within the Permian, Jurassic, or Triassic, but do not ordinarily follow a given horizon without frequent interruptions. Characteristic occurrences appear in fractured and brecciated beds or where plant fossils abound. More rarely the ores appear in fissures in the same formations where they were evidently deposited by ascending or descending atmospheric waters. Occasionally the ores have been leached and carried down into the lower strata. They appear to have no connection with thermal springs.

Origin.—In their present form the ores are assuredly epigenetic, but the evidence equally clearly points to their having been concentrated by atmospheric waters from small quantities

of metals disseminated in the rocks. It is believed, though the evidence of this is less direct, that the metals were carried down as sediments and solutions from older ore deposits in the adjacent continental areas. The sediments are in many cases of shallow water marine origin, but in part certainly land deposits, and often indicate arid conditions.

The waters which concentrated the ores are believed to have been mainly sodium chloride and calcium sulphate solutions containing sulphates and perhaps chlorides of copper and lead. Mineral association and geological features indicate low temperature deposition at shallow depths, probably well below 100° C., but below the zone of direct oxidation. Very likely these ores have been forming continuously since the establishment of active water circulation in the beds; in favorable places below the surface concentration may now be in progress.

COPPER AND LEAD DEPOSITS IN SANDSTONE.

European Occurrences.[1]—The European occurrences are confined to the Permian and the Triassic, both largely ages of arid climate and saline deposits.

The Russian Permian, extending far west from the Urals, consists in its lower division of sandstones, marls, in part marine, and conglomerates. The sandstones are rich in vegetable remains. Copper ores are found over wide areas, but have not been worked extensively of late years. They are said to average 0.9 per cent. copper. The chalcocite ores replace plant remains and tree trunks, or appear in the cement of the sandstones. The minerals mentioned are (besides secondary malachite and azurite): chalcocite, chalcopyrite, tetrahedrite (?), barite, vanadinite, volborthite (vanadate of copper and calcium).

Much interest has lately been taken in the copper deposits of the Khirgiz Steppes[2] between the Urals and the Altai in the

[1] For an excellent review of European localities, as well as complete index of literature, in part difficultly accessible, see Stelzner-Bergeat: Die Erzlagerstätten, 1904, pp. 388–439.

[2] Addiasseurch, A., "A Journey to Central Asia," *Trans. Inst. Min. and Met.*, 17, 1907–1908, pp. 498–522.

Karkaralinsk and Akmolinsk districts. Very rich copper ores have here been found in sandstones said to be Paleozoic, and they consist of malachite, azurite, bornite; little exact information is available. At Nankat, west of Kokand in Turkestan, new discoveries have been made of metallic copper in sandstones and gypsiferous marls of Tertiary age; fossil wood and chalcocite are also found.[1]

In Bohemia[2] the lower Permian (Rothliegende) along the south slope of the Riesengebirge contains similar ores. The lower beds carry chalcocite with a little silver, also some pyrite in several horizons of the arcosic rocks, which contain abundant plant remains.

The Permian of the Palatinate in Germany yields nodules of chalcocite and chalcopyrite.

Most important from an economic standpoint and curiously connected with the mineralization of the Permian is the "Kuperschiefer," or copper-bearing shale of Central Germany; this is described on a subsequent page (578).

Over a large part of Western Europe the Trias is a copper-bearing formation, and together with the copper more or less lead is found.

In England, at Alderley Edge and Mottram St. Andrews,[3] south of Manchester, copper ores have been mined. They occur in the cement of Triassic sandstones and conglomerates and consist of copper carbonates, galena, pyromorphite, and vanadinite; also some barite, manganese and cobalt. The ores are said to carry at most 1.4 per cent. copper. The mineral mottramite, a vanadate of copper and lead, was discovered at this place.

In Germany the Trias is divided in three parts: The lower variegated sandstone ("Buntsandstein"); the middle shell limestone (Muschelkalk); and the upper marls and sandstones (Keuper); of these the lower and upper divisions contain lead and copper ores.

[1] Beck, R., "Lehre von den Erzlagerstätten," 1909, 2, 172.
[2] Gürich, F., *Z. f. prakt. Geol.*, 1893, pp. 370–371.
[3] Phillips, and Louis, "Ore Deposits," 1896, pp. 266–269.

In Bavaria the Keuper contains galena and chalcopyrite in certain gypsiferous beds, and this is associated with a little zinc-blende and barite.

In Württemberg galena with a little oxidized copper ore and barite is generally distributed in the Corbula bed of the lower, gypsiferous Keuper. In the Palatinate, the littoral characteristics are plainly indicated and there is an abundance of fossil wood; in two horizons the sandstones contain galena and cerussite and were formerly worked.

In the "Buntsandstein" in Prussia and Lorraine, near Saarlouis and other places, a horizon known as the Voltzia sandstone, is particularly rich in lead and copper ores, which at times have been worked. The bed contains abundant plant remains. The minerals are cerussite, galena, chalcocite (?) and carbonates.

The best known deposits of the Trias are those of Commern and Mechernich, not far from Aix-la-Chapelle, in Prussia. Lead ores have been mined here for several hundred years, but it is reported that the mines may soon be closed. The ores are of low grade and are mined in open cuts by removing about 130 feet of overburden. In 1903 the ores averaged 1.5 per cent. lead (Stelzner-Bergeat). The ores are galena, cerussite, oxidized copper ores, with a little chalcopyrite and barite, the latter filling veins and veinlets in the sandstone. A little silver, nickel and cobalt are present. The thickness of the ore-bearing sandstone is about 20 meters. Very remarkable is the general occurrence of the galena in so-called "Knoten" or knotty concretions often enclosing several sand grains and sometimes bounded by the crystal faces of the galena. The epigenetic character of the ore is beyond doubt.

American Occurrences.[1]—On the North American continent

[1] Dumble, E. T., First Ann. Rept. Geol. Surv. Texas, 1889, p. 186.

Schmitz, E. J., "Copper Ores in the Permian of Texas," *Trans. Am. Inst. Min. Eng.*, 26, 1896, pp. 1051–1052.

Emmons, S. F., "Copper in the Red Beds," in Bull. U. S. Geol. Survey No. 260, 1905, pp. 221–232.

Emmons, W. H., "The Cashin Mine," Bull. U. S. Geol. Survey No. 285, 1906, pp. 125–128.

Jennings, E. P., *Trans. Am. Inst. Min. Eng.*, 34, p. 839. (Footnote continued on following page.)

copper ores are of widespread occurrence in the Red Beds of the Southwest. They occur in Texas, Oklahoma, New Mexico, Arizona, Colorado, Utah and Idaho, always conspicuous by the colors of malachite and azurite, but rarely proving of economic importance. More success than elsewhere has attended their exploitation in New Mexico.

The ore occurs in arkose sandstone, conglomerate, and clay-shale usually associated with plant remains and fossil wood. These strata were accumulated in shallow seas or as land deposits by a process of rapid degradation of adjacent land areas of the Rocky Mountain region. They have been referred to the Upper Carboniferous, Permian, Trias and Jura; in part the identification of horizons difficult on account of lack of fossils, but it seems certain that they are present both in the Upper Carboniferous and the Jurassic.

In Texas they appear over large areas in Permian sandstones and shales at several horizons, in strata rich in plant remains; covellite, chalcocite, chalcopyrite, and pyrite are the minerals mentioned. They are said to extend from 33° to 34° in latitude and from 98° to 100° in longitude.

In Oklahoma occurrences are noted by Tarr in red shales and sandstones of probable Permian age; in Stillwater and Payne counties. Fossil wood is often converted to chalcocite, sometimes with a shell of chalcopyrite; here unusually high silver values of 31 ounces per ton are reported and traces of gold.

In Colorado these ores have been observed at several places, notably at Red Gluch, Fremont County, from where Lindgren describes nodules of chalcocite with barite in black carbonaceous shale; sections show that the copper sulphide actually replaces the

Turner, H. W., *Trans. Am. Inst. Min. Eng.*, 33, p. 678.

Lindgren, W., Graton, L. C., and Gordon, C. H., "The Ore Deposits of New Mexico," Prof. Paper U. S. Geol. Survey No. 68.

Gale, H. S., "Geology of Copper Deposits near Montpelier, Idaho, Bull. U. S. Geol. Survey No. 430, 1909, pp. 112–121.

Lindgren, W., "Notes on Copper Deposits," Bull. U. S. Geol. Survey No. 340, 1907, pp. 170–174.

Tarr, W. A., "Copper in the Red Beds of Oklahoma," ECON. GEOL., 5, 1910, pp. 221–226.

shale, the lamination of which continues through the ore. Here also chalcocite replaces the coal of vegetable remains. The horizon is probably the uppermost Carboniferous. In northeastern Arizona, according to Gregory,[1] small quantities of oxidized copper ores are frequently seen in the La Plata sandstone. North of the Colorado they appear in the Carboniferous of the Kaibab Plateau, probably leached from once covering Red Beds. South of the Colorado S. F. Emmons has described a deposit of oxidized ores and chalcocite in the Aubrey limestone near Grandview, which he considers having been leached from once overlying Red Beds and carried down into the limestone by descending waters.

In southwestern Colorado copper is widely distributed in the La Plata sandstone (Jurassic) often with vanadium ores. W. H. Emmons has described the Cashin Mine in this formation near Placerville. The ores are here argentiferous chalcocite, covellite, and bornite, with some calcite. No igneous rocks are present and Emmons believes the ores to be leached from the Red Beds. There is an active circulation of water in the formation and springs with salt, sulphates, and hydrogen sulphide abound. A production of about 300,000 ounces of silver and 700,000 pounds of copper is recorded from this mine.

The greatest development of the copper-bearing sandstones is in New Mexico; considerable production from picked ore has been achieved at the Nacimiento deposits in the northern part of the State where the Red Beds, considerably disturbed, rest on pre-Cambrian granitic rocks which contain much older copper deposits. The beds have been referred to the Triassic on the evidence of fossil plants. According to F. C. Schrader (in pp. 68, U. S. G. S., cited above) most of the copper ores occur in the basal beds and are confined within a thickness of 25 feet in a reddish white sandstone rich in fossil wood, which is largely chalcocitized. A tree trunk 60 feet long with a basal diameter of 2½ feet is mentioned, which is almost wholly converted to copper glance. Besides malachite, azurite, and chrysocolla, there

[1] Gregory, H. E., oral communication.

is some barite, and, at one place, cerussite. The low grade ores have not been utilized.

According to the same geologist, in the Zuni Mountains in northeastern New Mexico the copper-bearing beds again lie at the base of the Red Beds, resting on pre-Cambrian gneisses which contain copper veins. The sandstones, shales, and marls for 30 to 60 feet just above the base of the beds contain oxidized ores and galena replacing wood.

L. C. Graton describes in detail the ores from Tecolote district, San Miguel County, which are partly in the Red Beds of the Upper Carboniferous (Abo formation), partly in a higher horizon, perhaps the Dakota sandstone. The calcareous cement of the arkose is replaced by chalcocite, bornite, chalcopyrite and pyrite, the replacement extending into the feldspar grains.

In the Oscura Range red sandstones, probably also of the Carboniferous Red Beds, contain chalcocite, bornite and chalcopyrite, in part as replacement of fossil wood. Turner mentions the occurrence of plant remains from this place, said to have been identified as the Triassic Podozamites crassifolia, the same cycad which is characteristic of the deposits at Abiquiu first studied by Newberry.

Graton believes, contrary to Turner, that the copper ores have been introduced into the strata from a number of dislocations cutting the sandstone.

Finally, H. S. Gale describes copper ores from southern Idaho which occur in the Ankareh Maroon shales and sandstones of the Trias or Carboniferous (equivalent to the Permo-Carboniferous of the Fortieth Parallel Survey). A thick limestone (including the Meekoceras beds) underlying these shales is believed to be Triassic by some geologists.

There are then at least two main cupriferous horizons in the Southwest: (1) The Upper Carboniferous Red Beds, equivalent to the Permo-Carboniferous, or the Abo formation; (2) the undoubtedly Jurassic, La Plata sandstone.

The silver deposits in the supposedly Triassic sandstones of

Silver Reef[1] in Southern Utah (Harrisburg district), which created quite a boom about 1880, are now only worked on a small scale. The ores were silver chloride above the water level and native silver and argentite in depth; copper was also present, and selenium is reported. Plant remains were abundant. On the whole a secondary concentration from a primary argentiferous chalcocite is the most probable explanation. It has already been emphasized that the chalcocite universally carries silver, though in the ordinary occurrences the tenor is rarely above 10 ounces per ton.

South America.—The well known and long worked copper deposits of Coro-Coro[2] in Bolivia, a series of standstones, believed to be of Permian age, here contain several beds impregnated with native copper with some native silver, domeykite and chalcocite, also much gypsum. The copper-bearing horizons are much lighter in color than the prevailing deep red sandstones.

According to Steinmann the strata are of Cretaceous age and the copper was introduced by hot waters derived from an intrusion of diorite. Nevertheless the descriptions suggest strongly that the deposits belong in a different class.

Africa.—Sufficient information is not at hand to decide whether the recently opened Katanga[3] ores of southeastern Belgian Kongo, near Rhodesia, belong in this division. Large masses of high grade oxidized copper ores are contained in sand-

[1] Roelker, "The Silver Sandstone District of Utah," *Trans. Am. Inst. Min. Eng.*, 9, 1881, pp. 21–33.

Rothwell, "The Silver Sandstone Formation of Silver Reef," *Eng. and Min. Jour.*, 29, 1880, pp. 25, 48, 79.

Newberry, "Report on the Property of the Stormont Silver Mining Company," 30, 1880, p. 269; 21, 1881, pp. 4–5.

Kemp, "Ore Deposits of United States," 1900, p. 334.

[2] Older literature: See Stelzner-Bergeat (I.), p. 419.

Steinmann, G., *Rosenbusch Festschrift*, 1906, pp. 335–368.

[3] Farrell, J. R., "The Copper and Tin Deposits of Katanga," *Eng. and Min. Jour.*, 85, April 11, 1908, p. 564.

Buttgenbach, H., "Les gisements de cuivre de Katanga," *A. S. Geol. de Belge*, 31, 1904, p. 515.

Ball, S. H., and Shaler, M. K., "Mining Conditions in the Belgian Congo," *Trans. Am. Inst. Min. Eng.*, 1910.

stones, shale, and limestone, probably of Paleozoic age. The ores are of high grade (8 to 12 per cent. copper) and are stated to contain a little gold and silver; some manganese, cobalt, and nickel are present. Barite and quartz appear as gangue minerals. A deposit at Ruwe, in the same general region described by Ball, contains in a sandstone, a most curious association of ores yielding gold, platinum, silver, palladium, vanadium, nickel, lead and copper, the last two metals as vanadates. In some ways this deposit suggests the type now under description.

GENESIS.

The epigenetic character of the copper deposits in sandstone is proven beyond reasonable doubt. The replacement of coal, carbonaceous shale, and calcareous sandstone cement by chalcocite is proven. The gangue minerals are few and quartz is conspicuously absent. Barite in small amounts is rather common. Irregularity in dissemination is typical, though the ores often follow certain horizons rather persistently. The entire independence of the occurrence of igneous rocks is marked. The difference between these deposits and the ordinary type of fissure vein is striking, and they can not have been formed in the same manner. It is necessary to explain why chalcocite is characteristic of the first and chalcopyrite of the second type.

The occurrences are mainly on the flanks of older continental areas containing pre-Cambrian copper deposits; the sandstones were rapidly deposited as arkoses indicating a long epoch of rock decay, the products of which were rapidly swept away during a following arid epoch. Considering the evidence as a whole the sedimentary deposits must contain finely divided copper ores in part from solutions derived from the land area, in part as cupriferous detritus. When atmospheric waters charged with salt and gypsum searched these beds they must have taken this copper into solution and concentrated it in certain horizons when reducing substances like coaly vegetable matter were available. In most cases the solution probably contained the copper as sulphate, though where much salt was present it might well

have been transformed into chloride; or where H_2S was available it might have been carried in solution as sulphide.

It does not follow that all deposits of copper ores in sandstone and shale belong to this class here described, for an impregnation by ascending thermal solutions of foreign origin is a possible contingency in some instances.

In the precipitation the most important chemical reactions were those between the carbonaceous matter of plant remains and the calcareous cement or the kaolin in the sandstone on one hand and the cupriferous solutions on the other hand.

VANADIUM ORES IN SANDSTONES.

The preceding pages show that the copper deposits often carry some vanadium as vanadinite or volborthite. Lately vanadium with some uranium has been shown to be common in certain sedimentary horizons in Colorado and Utah. The deposits in Western Colorado are now worked and experimental plants for their reduction are being erected at Newmire, near Placerville.[1] Some of the sandstone near Placerville contained 3.50 per cent. V_2O_3 and 0.05 per cent. UO_3. Shipments are said to have contained as much as 11.5 per cent. U_3O_8 and 6.40 per cent. V_2O_5, but on the whole the grade is probably low.

In all these states the vanadium ores appear to occur in the Jurassic limestone of the La Plata formation. The best known localities are near Placerville in the La Sal, Paradox, and Sindbad valleys. The ores follow certain horizons or appear in fissures and brecciated places; they are often associated with plant

[1] Hess, F. L., "Min. Res. U. S.," 1907, p. 721.

Merrill, G. P., "Non-metallic Minerals," 1904, pp. 299–320.

Hillebrand, W. F., and Ransome, F. L., "Carnotite, etc., in Western Colorado," *Am. Jour. Sci.*, 4th Ser., 10, 1900, pp. 120–144. In Bull. U. S. Geol. Survey No. 262, 1905, pp. 9–13. State Bureau of Mines, Colorado, Rept. 1905–1906.

Boutwell, J. M., in Bull. U. S. Geol. Survey No. 260, 1905, p. 205.

Gale, H. S., "Carnotite in Western Colorado," in Bull. U. S. Geol. Survey No. 340, 1908.

Gale, H. S., "Carnotite in Rio Blanco County, Colorado," in Bull. U. S. Geol. Survey No. 315, 1906, pp. 110–117.

remains. The occurrences are all within the Great Plateau province of horizontal or gently inclined strata.

The most prominent mineral is the bright yellow powdery carnotite, to which Fuchs and Cumenge give the formula $2U_2O_3$, V_2O_5, K_2O, $3H_2O$, but Hillebrand doubts whether the formula is as simple as this. One of his analyses of carnotite from Roe Creek gave:

UO_3	54.89	PbO	0.13
V_2O_5	18.49	CuO	0.15
CaO	3.34	MoO_3	0.18
BaO	.90	H_2O	4.54
K_2O	6.53	CO_2	0.56
		Insoluble	7.10

Copper as green stains of malachite, brochantite and azurite is commonly present in the deposits and frequently also lead. Hildebrand also found some molybdenum, arsenic, a selenite of copper, and some manganese. Roscoelite, a vanadium mica develops in the calcitic or kaolinic cement of some of the sandstones in southwestern Colorado. This mineral carries only a small amount of oxide of vanadium, but is present in the richest olive-colored beds to the extent of 20 per cent. Lately a black mineral of doubtful composition, probably a vanadium oxide, has been found in this region and it is indeed possible that carnotite is a secondary product of an unknown primary vanadium mineral. The roscoelite has probably not been altered since its first deposition. In the Utah beds Boutwell found vanadates of copper such as volborthite and calcio-volborthite.

Not similar to these deposits, yet perhaps of a similar origin, are the recently discovered important vanadium deposits at Minasragra,[1] near Quisque, Province of Pasco, Peru, described by D. F. Hewett.

The vanadium sulphide, patronite, occurs here on a large scale as greenish black masses associated with a hydrocarbon and a

[1] Hewett, D. F., "Vanadium Deposits of Peru," *Trans. Am. Inst. Min. Eng.*, 40, 1909, pp. 274–299.

Hillebrand, W. F., "The Vanadium Sulphide Patronite," *Jour. Am. Chem. Soc.*, 29, 1907.

Hillebrand, W. F., *Am. Jour. Sci.*, 4th Ser., 24, 1907, p. 141.

peculiar nickel-bearing pyrite. An analysis of the patronite gave 58.79 per cent. sulphur, 19.53 per cent. vanadium, 0.18 per cent. molybdenum, 1.87 per cent. nickel, and 3.47 per cent. carbon. The mineral forms a vein with much bitumen and clay in gently dipping cretaceous strata. Igneous rocks are present in abundance and may be responsible for the peculiar development of a new type of ore.

Genesis.—Traces of vanadium are found, according to Hillebrand, in most igneous rocks. Smaller quantities occur as oxidation products in many ore deposits, mostly as vanadinite or descloizite. More abundantly vanadium occurs in sedimentary rocks such as clays and shales; it is also concentrated in coal; the ashes of many varieties are rich in vanadium.[1] This peculiar relationship has not been fully explained; at any rate the processes of weathering and vegetation appear to be favorable to the concentration of vanadium; and, to some extent, uranium shares in this behavior. The association of vanadium and copper in the ore-bearing sandstones has already been emphasized, as well as their frequent occurrence with coal or vegetable remains.

Viewing the evidence as a whole the vanadium deposits described above are probably products of concentration, by surface waters of small quantities of the metal distributed through littoral beds or land deposits of sandstone and clays.

THE COPPER-BEARING SHALES OF MANSFELD.[2]

The celebrated cupriferous shale (Kupfer schiefer) of Mansfeld in central Germany, though not identical with the deposits described in this chapter, presents most interesting analogies to them.

A flourishing mining industry is still based on the "Kupfer schiefer," the annual ore production being approximately 700,000 metric tons of ore containing between 2 and 3 per cent. of copper.

[1] See Clarke, F. W., "The Data of Geochemistry," 1907, p. 611. A coal from the copper deposits in sandstone of Red Gulch, Colorado, contained, according to Hillebrand, 0.18 per cent. vanadium.

[2] Best description with literature in Stelzner-Bergeat: "Die Erzlagerstätten," 1, pp. 391–417.

The first stratum deposited in the subsiding basin of the Upper Permian in central Germany was a marine conglomerate of slight thickness. "Above it extends like a black shroud the thin bed of cupriferous shale, one of the most remarkable products of the geological ages. Characterized by its fauna as a shallow-sea deposit, full of plant remains carried in from adjacent coasts, the formation bears the stamp of an organic mud deposit admixed with an organic precipitation."[1]

Above the cupriferous shale, which is less than 1 meter thick, extends a marine limestone (Zechstein), 8 to 10 meters thick, and above that lie the great gypsum and salt masses of the uppermost Permian. Folding and faulting have since affected the beds, and the mining now follows the inclined strata to a depth of 500 meters.

The cupriferous bed averages 50 centimeters in thickness, but only the lower part of 20–30 centimeters is mined.

The ores are sulphides, in minute distribution through the shale giving it a bronzy appearance. Chalcopyrite predominates, but there is also bornite, pyrite, chalcocite, rarely galena and tetrahedrite. Small quantities of nickel, cobalt, selenium, vanadium, and molybdenum have been recognized; there is also 0.010–0.015 per cent. of silver. Zinc is present and in the upper part of the bed, not mined, there is more zinc than copper. An average analysis is as follows:[2]

AVERAGE ANALYSIS OF CUPRIFEROUS SHALE.

(Dr. Haase, Analyst.)

SiO_2	33.15	Ag	0.014
Al_2O_3	17.3	Ni	0.018
CaO	10.4	S	2.31
MgO	1.0	CO_2	9.24
Fe	2.6	H_2O	1.7
Zn	1.276	Bitumen	9.06
Cu	2.75		

There is about 3 per cent. K_2O and 1 per cent. Na_2O; lead amounts in place to 1.50 per cent., manganese to about 0.25 per cent.

[1] Beyschlag, F., In "Deutschlands Kalibergbau," 1907, p. 4.
[2] Stelzner-Bergeat, 1, p. 396.

There is practically no gangue, except veinlets of gypsum and barite. The bed is cut by faults, which in places contain barite, anhydrite, calcite, niccolite, pyrite and chalcopyrite, and near these (the so-called "Rücken") the metal content is subject to enrichment, impoverishment or removal upwards in adjacent beds. Bergeat asserts that these changes take place on secondary fissures and cracks.

There has been much controversy about the Mansfeld deposits. The majority of geologists regard them as sedimentary and syngenetic: v. Groddeck, Stelzner, Freiesleben, and von Cotta held this view, and it is shared by Bergeat. Posepny and Beck believe them epigenetic and probably introduced into the shale from the "Rücken."

The "Kupfer schiefer" is certainly not an ordinary marine deposit precipitated from the sea water.[1] It was laid down in a shallow sea full of decaying vegetable and animal remains into which cupriferous waters from the surrounding littoral was discharged, most likely sulphate solutions derived from the eruptives of the early Permian epochs. No one can read the description of the great uniformity of distribution without being impressed with the very strong arguments for a syngenetic origin.

At the same time it is proper to call attention to the characteristic presence of nickel, cobalt, vanadium and selenium which recalls the epigenetic deposits in sandstone so abundant around the shores of the Permian sea, in Bohemia and Russia, for instance. The Mansfeld basin was simply then the final collecting place of the solutions derived from adjacent desert shores.

[1] It is well known that sea water does contain a little copper, as shown among others by Dieulafait (*Am. Chim. phys.*, 5th Ser. 18, 1879, p. 359; also *C. R.*, 90, 1573; pp. 96, 70, 101, 1297), but it seems utterly insufficient to account for the Mansfeld deposits.

THE ORIGIN OF THE LEAD AND ZINC ORES OF THE UPPER MISSISSIPPI VALLEY DISTRICT.

PART II.

GUY HENRY COX.

OUTLINE OF PROPOSED HYPOTHESIS FOR ORIGIN OF THE ORES.

In outline the proposed hypothesis for the origin of the lead and zinc ores of this district follows the earlier writers in so far as it is believed that the ores existed originally as more or less finely disseminated particles in the pre-Cambrian igneous rocks which constituted the land areas somewhere to the northeast in Ordovician and pre-Ordovician times; that the metallic compounds were leached out during the ordinary process of weathering of these rocks, carried to the sea by the streams, and there deposited with the sediments through the reducing power of organic matter.

Farther than this the writer is not in agreement with any of the above authors with the possible exception of Winslow in that he believed the ores to have been deposited from descending solutions. It is thought that the ores were deposited from the Ordovician sea with the Maquoketa shale; that the precipitation of the ores was due to the reducing action of the organic matter contained in these shales; that with the erosion of the Maquoketa shale the ore particles were taken into solution, carried downward and deposited in the openings in the Galena formation by ordinary meteoric waters; and that the ores have since undergone some secondary concentration.

In the ultimate source of the ores there is perfect accord with the conditions as expressed by Bain[1] in the following paragraph.

"For the original source of the zinc and lead we must doubtless look to the crystalline rocks of the Lake Superior region. It is from this region that the lime, magnesia, and sand now found in the formations of the

[1] Bain, H. F., "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey, No. 294, p. 129.

zinc and lead region came. In Canada and northern Minnesota there are scattered deposits of the ores of these metals in the older formations, which were exposed to erosion in Platteville and Galena times. During these epochs the region was apparently base-leveled and the drainage from a wide area reached the bordering seas. Mechanical erosion was at a minimum and solution was active. Magnesium, lead, and zinc have many chemical reactions in common, and it would seem inevitable that where one of these metals was transported in quantity from the land to the ocean, the others would follow, and that certain amounts would be deposited."

In regard to the immediate source of the ores it is proposed to show that of all the formations known to have been present in this district, the Maquoketa shale is the most favorable.

The reducing power of organic compounds, especially those of organic acids and gases, and its strong precipitating action on certain metallic elements when in solution as sulphates or carbonates, is well known. All of the late writers have appealed to this to account for the precipitation of the lead and zinc ores of this district. It is, I believe, a well-recognized fact that as a rule those unaltered sedimentary formations which have the highest organic content also contain the largest amount of original metallic sulphides, as illustrated by the omnipresence of marcasite in coal and coal slates. Zinc blende itself is not an uncommon occurrence in such formations as has been mentioned by Bain[1] and Buckley and Buehler.[2]

If a series of analyses of some unaltered sedimentary formation were available, it might well be expeceted that those portions which contained the most organic matter would also contain a correspondingly larger amount of original metallic sulphides. In other words, other things being equal we might expect to find a rather close relation between the amounts of organic matter and metallic sulphides. Unfortunately such analyses are not available. Also, very few analyses are complete, especially in these particulars. The comparison of the analyses of similar

[1] Bain, H. F., "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey, No. 294, p. 131.

[2] Buckley and Buehler, "Geology of the Granby Area," Missouri Bureau of Geology and Mines, Vol. IV., 2d series, p. 81.

rocks from different localities is always open to the objection that they may not have been formed under exactly the same conditions. The only method left, then, to make such a comparison is to use the averages of a large number of analyses on the assumption that this would give the average conditions and bring out such a relation if it exists. Such a summary of analyses is given by Clark.[1]

	A	B	C	D	E	F	G
Fe_2O_3	4.00	4.04	4.03	1.08	1.39	.54	.77
FeO	1.74	2.90	2.46	.30	.84	Undet.	Undet.
(Total Fe)	(4.15)	(5.08)	(4.72)	(.99)	(1.62)	(.38)	(.54)
H_2O above 110° C.	3.45	3.82	3.68	1.33[1]	1.47[1]	.56[1]	.88[1]
Carbon[2]	.69	.88	.81				

[1] Includes organic matter.

[2] Of organic origin.

(Collected by G. K. Gilbert, assisted by G. W. Stose, of the U. S. Geol. Survey and analyzed by Dr. H. N. Stickes.)

A. Composite analysis of 27 Mesozoic and Cenozoic shales.
B. Composite analysis of 51 Paleozoic shales.
C. General average of A and B.
D. Composite analysis of 253 sandstones.
E. Composite analysis of 371 sandstones.
F. Composite analysis of 345 limestones.
G. Composite analysis of 498 limestones.

Iron is closely associated with the lead and zinc ores in all parts of the district, being unquestionably of similar origin and having undergone the same changes—solution, transportation and deposition. If then its precipitation was due to the same cause as that of the ores, other things being equal, an increase in the amount of iron would correspond to a similar increase in the amount of lead and zinc. Therefore, in a set of analyses such as the above, in which PbO and ZnO were not determined, the varying amounts of iron might be considered as indicative of the varying amounts of lead and zinc that would have been present if the conditions were favorable for their deposition.

A close relation between the amounts of ferrous iron or total iron and the amount of organic matter, "carbon," is strongly

[1] Clark, F. W., Bull. U. S. Geol. Survey, No. 228, p. 20.

indicated in A, B and C, which, together with the almost perfect continuation of this relation through D, E, F and G (a grand total of 1,545 analyses) seems to be sufficient evidence on which to establish the rule that, other things being equal, the amount of iron, lead and zinc which exist in a sedimentary formation as original minerals, *i. e.*, deposited at the same time as the for-

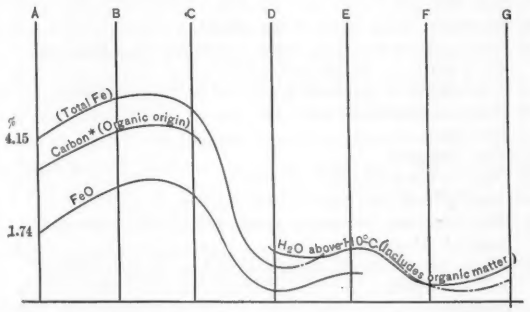

FIG. 89. Plot showing relation between metallic content and organic matter.

mation in which they exist, varies directly with the amount of organic matter so long as the metallic content of the sea is not exhausted.

Organic Content of the Maquoketa Shale.—Because the Maquoketa shale has been almost entirely eroded from the lead and zinc district of the upper Mississippi Valley the occurrence, in places at least, of considerable organic matter within it has not been generally noted. The Natural Carbon Paint Company of Freeport, Ill., was organized to manufacture paint with certain by-products from a so-called oil rock obtained from near the towns of Elroy and Mt. Carroll, Ill. This material is black when wet and of a light bluish gray color when dry, could be lighted with a match, and burned as readily as the oil rock of this district and with a similar petroleum odor. This shale came from the Maquoketa formation and contained 20 per cent.

organic matter.[1] The shale from Elroy came from a shaft about 36 feet deep on the farm of R. Stadermann, SW. ¼, Sec. 13, T. 27 N., R. 6 E. Mr. Stadermann gives the following section for this shaft which penetrates the lower portion of the Maquoketa shale.

	Ft.	In.
14. Soil	3	
13. Yellow, sandy gravel with many marcasite nodules	4	
12. Blue hard pan	6	
11. Soapstone (a light colored clay shale)	6	
10. Black carbonaceous shale, burns readily leaving a black ash. Gives much gas by destructive distillation	3	
9. Conglomeration (probably a mixture of clay and shells)		3
8. Flat containing much marcasite	3	
7. Blue clay		6
6. Hard limestone	1	6
5. Black carbonaceous shale as above	3	
4. Layer of marcasite nodules with clay		3
3. Hard limestone containing pyrite, galena and a two inch sheet of sphalerite	3	
2. White, loose material containing pockets of iron sulphide and zinc blende	4	
1. Limestone	?	

Maquoketa shale so organic that it will burn readily is reported from west of North Buena Vista, Ia. In sinking the new shaft of the Avenue Top mine at Dubuque the twelve feet of Maquoketa shale passed through was very organic in nature.

It now having been established that both the Maquoketa shale and the oil rock are organic formations, and inasmuch as both formations have been advanced as the source of the ores because of their organic material, it would be of interest to determine which of the two contained the more organic matter. Chamberlin[2] gives three partial analyses of oil rock which show 40.60, 18.31 and 15.76 per cent organic matter. F. F. Grout found 20.85 per cent. in a sample from near Platteville, Wis. These four analyses give an average of 23.88 per cent. If we consider 175 feet as a minimum average of the former thickness of the

[1] Analysis furnished by the Natural Carbon Paint Company, Freeport, Ill.
[2] Chamberlin, T. C., "Geology of Wisconsin," Vol. 2, 1877, pp. 680-681.

Maquoketa shale over the district, it would require but 1.36 per cent. of organic matter in the shale to equal that contained in the oil rock, considering the latter to average one foot thick over the district. Such highly organic beds as found at Elroy and Mt. Carroll, Ill., may be exceptional and more or less irregular in their occurrence, but the general organic character of the Maquoketa shale as shown above together with the consideration that the shale has had a thickness of 175 feet while the oil rock will average a foot or less in thickness for the general mining district, shows very clearly that the shale contained a far greater total amount of organic matter. If then the Ordovician sea were as rich in these materials during the Maquoketa period as it was during that in which the Galena limestone was formed, the Maquoketa shale would, without question, have been the more favorable place for the ores of this district to have been precipitated.

The determination of small amounts of lead and zinc in iron-bearing organic shales becomes a very difficult matter, so that only a few analyses have been made to date. The following analyses were made by R. D. Hall for the Wisconsin Geological and Natural History Survey at the writer's request.

	Pb	Zn	BaO
1. Shale from Mt. Carroll, Ill.....	0.016	0.088	0.032
2. Shale from Elroy, Ill.....	0.00	0.049	0.023
3. Shale from Graf, Ia.....	0.014	0.024	0.039

The first two samples came from the lower portion of the Maquoketa shale, while the third is a mixture of a number of grab samples taken from the section shown previously and belongs to the middle portion of these shales. None of these samples was collected for the purpose of analyzing them for lead and zinc.

Pieces of blende are reported to have been found in many places in the Maquoketa shale. In the Dubuque district flats of blende and iron sulphide have been found at the Galena-Maquoketa contact and fair sized pieces of blende 6 or 8 feet up in the shales. At the Granville mine, 2½ miles north of Scales Mound, Sec. 23, T. 29 N., R. 2 E., pieces of sphalerite an inch and over

in diameter, associated with iron sulphide and barite, were found throughout a 150-foot tunnel in the shales, about 100 feet above the Galena dolomite and about 60 feet below the surface. At the Chicago Great Western cut one mile east of Elizabeth, blende and considerable iron sulphide were found at a depth of about 25 feet. In the Illinois Central cut at Scales Mound pieces of blende varying from small stringers to a hen's egg in size were found associated with iron sulphide throughout the shale exposure, which consists of the lower 25 feet. In fact, at every place at which the shales have been examined with this purpose in view ore has been found, either in pieces of sufficient size to be determined by the eye, or by analyses as given above.

In all the theories so far advanced concerning the origin of these ores it has been impossible to show that the ores were original in the proposed source. Davis in his consideration of the oil rock, by showing the presence of crystals of galena and sphalerite in this impervious shale, came nearer than any other writer to showing that the ores were original in the proposed source. Many analyses have been made of limestones in general to show that they contain small amounts of lead and zinc, yet because of their porous character and the free circulation of water through them, especially in this district, it is impossible to say that even the small percentage shown by the average of these analyses is original.

Even if it were true, and it probably is, that the oil rock and limestones in general contain small amounts of original lead and zinc compounds, it is believed that the Maquoketa shale offers a more probable source for the ores because the occurrence of these ores in the railroad cuts at Elizabeth and Scales Mound, in the Granville mine, at Elroy, and Mt. Carroll, in such an impervious formation and at depths ranging from 20 to 100 feet below the surface, precludes any possibility of their having been introduced after the deposition of the shale. Certain it is that the ores could not have come up from the Galena dolomite and it seems equally certain that they could not have been carried down from the Niagara dolomite through a thickness of 175 feet of such impervious shale.

At my suggestion Mr. I. M. Buell made an estimate of the amount of impregnation of the rock that would occur, if the entire quantity of ore taken from the Potosi district were uniformly distributed through the adjacent rock. This district was selected because (1) it has been one of the most productive, (2) has definite outlines, (3) a somewhat uniform distribution of crevices, and (4) is withal one of the most concentrated districts of the whole region. In determining the limits of the district, a margin outside the outermost crevices was allowed equal to half the average distance between the crevices, *i. e.*, the outside crevice was supposed to draw only as much from the territory outside as from that between it and its neighbor crevice. As the basin occupied by the district extends some distance on every side, this is a very moderate assumption. Furthermore, it was assumed that only 100 feet in depth had been leached in the derivation of the ores, although probably twice that amount of rock originally lay above the base of the deposit. The result was *one fourteen-hundredth of one per cent.*, or a little more than seven millionths of the rock, a quantity that may seem surprisingly small to those who, by dwelling on the relative value of the ores magnify their relative quantity, a quantity certainly small enough to answer certain inconsiderate objections to the theory of derivation of the ores from the enclosed rock, based on the want of ocular evidence of their metalliferous character.[1]

If we assume the Maquoketa shale to have averaged 175 feet thick over the whole district, it would then require, according to the above figures, 0.00000406 per cent. of original metallic sulphides in the shale to account for the ore mined in the Potosi district. Or, if we assume that half of the material was lost in transfer from the shales to the dolomite, 0.00000812 per cent. If we may assume that the Potosi district is a representative one, then these figures are applicable to the district as a whole.

It is possible to check the above figures by taking into account the amount of shale that has been available, having been entirely eroded, and comparing it with the amount of ore produced to date, making a liberal allowance for that which may still be produced. Such a computation must necessarily be crude, but it will be seen that even when liberal allowances are made to cover all possibilities of ore being lost in the transfer and of ore yet to be discovered, the result will still be below rather than above the figures derived from Chamberlin's estimates.

[1] Chamberlin, T. C., "Geology of Wisconsin," Vol. 4, p. 538, 1882.

If a polygon be drawn so that its angles are at Blanding and Stockton, Ill., Monroe and Highland, Wis., and Guttenburg, Ia., it will include the general mining district, although ore has been found in paying quantities outside this area, as south of Elizabeth and Stockton, Ill., north of Monroe, Wis., north of Highland, Wis., southwest of Dubuque, Ia., etc. The minimum estimate of the mining district would then be about 2,025 square miles. Considering the Maquoketa shale to have averaged 175 feet thick over the area, and to have had a specific gravity of 1.9, there would have been, roughly, 586,590,000,000 tons of shale to furnish the ore.

PRODUCTION OF LEAD AND ZINC ORE.

Lead Ore.	Tons.
Total production up to 1904[1]	611,975,
Amount produced in 1904[4]	1,000
Amount produced in 1905[4]	1,500
Amount produced in 1906[3]	2,100
Amount produced in 1907[2]	4,000
Amount produced in 1908[2]	4,000
	624,575

Zinc Ore.	Tons.
Total production up to 1905[1]	450,000
Amount produced in 1905[1]	33,000
Amount produced in 1906[2]	43,000
Amount produced in 1907[2]	54,000
Amount produced in 1908[2]	59,000
	639,000
	624,575
Total ore	1,263,575

This gives a grand total of 1,263,575, or roughly, 1,264,000 tons of lead and zinc ores, which, although not all mined as sulphides, were originally sulphides and can be so classed here, mined up to 1909. This amount of ore would require an original

[1] Bull. U. S. Geol. Survey No. 294.

[2] Estimate based upon the production of Wisconsin as given in Mineral Resources, 1908.

[3] Mineral Industries, 1906.

[4] Estimate.

percentage of 0.000002155 in the shale. If, for the sake of argument, we assume that there is as much ore left as mined, it would require 0.00000431 per cent.

If we assume that there is as much ore left as mined and that half was lost in the transfer from the shales to the dolomite, it would necessitate only 0.00000862 per cent. of original metallic sulphides.

While the above percentages are approximately one half of those obtained by Chamberlin for the Galena dolomite, they are almost identical with those obtained by applying Chamberlin's method to the Maquoketa shale, *i. e.*, considering 175 feet of shale as against 100 feet of the dolomite.

On a previous page it was stated that where the Maquoketa shale had been examined in respect to its metallic content, lead and zinc sulphides had either occurred in pieces sufficiently large to be determined by the eye, or have been shown to be present by chemical analyses. In three cases 0.104, 0.049 and 0.038 per cent. of combined lead and zinc, or 0.1485, 0.073, 0.0522 per cent. of combined lead and zinc sulphides. Showing conclusively that there can be no question concerning the adequacy of the Maquoketa shale as the source of the ores.

It is a fact generally recognized by all who are familiar with this district, that there is and has been in the past a general order of deposition of the ores, both as to their vertical distribution and in their occurrence on the sides of openings. The large predominance of the lead over the zinc mined in the early days was not necessarily due to the greater value of the former, but also to the characteristic occurrence of the lead near the surface, while the zinc and iron are found at a greater depth, usually below the water table, there being a marked increase in the relative amount of iron sulphide as compared with that of zinc at the base and sides of an ore deposit. Thus the general order of occurrence of the ores from the surface downward is galena, sphalerite and iron sulphide.

Solutions which have passed through the small pores of a limestone for a considerable distance as postulated by the Galena-oil

rock theory could not be other than alkaline or neutral in nature. Meteoric waters directly from the surface carrying metals which have been taken into solution by the oxidation of sulphides are characteristically acid, particularly so when carrying iron, the oxidation of the sulphide of which forms free sulphuric acid.

In the ordinary qualitative or quantitative chemical determination of a lead and zinc solution, the lead is first precipitated in the presence of an acid, and then the zinc in the presence of an alkali. If the lead had not first been removed, both of the metals would have been precipitated together from the basic solution. In accord with this Buckley and Buehler[1] have shown that the sulphides of lead, zinc and iron are precipitated from a neutral solution and lead and zinc from an alkaline solution in an intimate mixture; while if the solution is acid the lead sulphide is thrown down first, the zinc sulphide second, and the iron sulphide last.

From the above it is clear that the vertical distribution of the present ore bodies cannot be explained by their direct precipitation from such solutions as are necessitated by the Galena-oil rock theory and all of its modifications, but that this order is such as would result from the precipitation of the ores from descending acid solutions such as would have been present if the ores have been derived from the Maquoketa shale.

A similar order of deposition is also shown in the sheets lining cavities and openings in general; the first to be deposited, next to the wall rock, being iron sulphide, pyrite and marcasite, then sphalerite and galena in order. So characteristic is this banding that there seem to be but two possible explanations for it; either it represents the order of precipitation of these metals from a common solution, or the solutions which first reached these points had been depleted of their lead and zinc and contained only iron. Those who favor any of the oil rock theories might claim that the former was the true explanation and so explain the vertical distribution of the ores as having been deposited from

[1] "Geology of the Granby Area," Missouri Bureau of Geology and Mines, Vol. IV., 2d series, p. 107.

ascending solutions, were it not for the fact that field observations indicate that the iron sulphide tends to mark the extreme limit to which the mineralizing solutions have penetrated and not the point at which they have been introduced. This being true, it follows that the iron sulphide is deposited next to the country rock because it is the most soluble of these metals and is therefore liable to be carried first, or because it is the least readily precipitated and would therefore be carried the farthest. The second layer is composed of sphalerite because it is more soluble and less readily precipitated than the galena. As the surface and water table are lowered by erosion the lead and zinc are carried farther and farther down, resulting in the banding described above.

For the upper Mississippi Valley lead and zinc district three possible reasons for the localization of the ores in the sediments have been outlined[1] and are here considered in the discussion of the Maquoketa shale as the source of these ores.

Local Abundance of the Metals in Solution.—While we have no reason to suppose that the Ordovician seas were any richer in metallic compounds than the seas of the present time, there is good reason for believing that there did exist, as now, segregations of minerals within the earth's crust with the result that some districts were rich in some of the metallic ores while others were destitute; and that the water[2] of the streams draining such mineralized areas would contain abnormal percentages of these metals in solution, with the result that at the mouths of such streams, or within bays into which they may have emptied, there would exist a local abundance of the metals in solution. The evidence for this hypothesis may then be briefly summarized as follows:

1. It is known that the water of rivers draining mineralized areas are abnormally rich in the metals of the region drained.

2. The presence of an unconformity between the Maquoketa and Galena formations, found elsewhere and indicated here by an

[1] Bain, H. F., "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey, No. 294, p. 133.

[2] See Chamberlin and Salisbury, "Geology," Vol. I., 1904, table opposite page 102, for variations in the compositions of river waters.

abrupt change of fossils and the presence of what has been taken to be small pebbles near the base of the Maquoketa shale and the large amounts of organic matter within it, indicate shallow water conditions, such as embayments or areas near shore.

3. The irregular distribution of the lead and zinc ores over the district and the occurrence of copper at Mineral Point, Wis., where it has been mined to the value of half a million dollars, and near Gratiot,[1] Wis., while even traces are almost entirely lacking in the rest of the district, show conclusively that there has been either a change in the character of the solutions or of the precipitating agents. Were it possible to determine what the character of the Maquoketa shale (precipitating agent) was at these points, it having been eroded, this argument would be definite. Certain it is that there is no apparent change in the character of the Galena dolomite or the oil rock at these points so that if this could be shown to be true of the overlying shale as well, it would follow almost as a corollary that, if there has been no change in the precipitating agent, there must have been a change in the character of the solutions, both as to amounts and kind of metals contained.

Local Abundance of the Organic Reducing Matter. The Maquoketa shale and the oil rock are the two most organic formations ever known to have been present in this district. There are, however, many formations in other districts which contain organic matter in considerably greater quantities than either of these and yet are not known to have been the sources from which ore deposits have been derived. It is therefore evident that, while these rocks are highly organic, "local abundance of organic reducing matter" is not sufficient in itself to account for the location of the district.

Locally Peculiar Organic Matter, Leading to Particular Efficiency in Producing Deposition.—Just what is the reducing power of organic shales in general is not known. Bain[2] by the following experiment has attempted to show that the oil rock has an exceptional precipitating power.

[1] Cox, G. H., "Copper in Southwestern Wisconsin," *Mining and Scientific Press*, Vol. 99, No. 18, p. 529, October 20, 1909.

[2] Bain, H. F., "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey, No. 294, p. 135.

To one fourth gram of air-dried oil rock and 100 cubic centimeters of water was added .005 gram of iron in the form of ferric sulphate. This was acidified with 5 grams of H_2SO_4, and a similar portion was rendered alkaline with .1 gram KOH. After standing a week the amount of iron present as a ferrous salt was determined with $KMnO_4$. It was found that in the acid solution the amount was .0035 gram and in the alkaline .0012 gram.

In order to compare the relative reducing powers of the Maquoketa shale and the oil rock the following test,[1] which is exactly the same as that used by Bain for the oil rock, was made.

To one fourth gram of air-dried Maquoketa shale and 100 cubic centimeters of water was added .005 gram of iron in the form of ferric sulphate. This was acidified with 5 grams of H_2SO_4, and a similar portion was rendered alkaline with .1 gram of KOH. After standing a week the amount of iron present as a ferrous salt was determined with $KMnO_4$. It was found that in the acid solution the amount was .0037 gram and in the alkaline .0017 gram.

The result of the above experiment shows that the organic matter of the Maquoketa shale and that of the oil rock have practically the same reducing power, which is, probably, abnormally high for shales in general. However, it should be borne in mind that if organic matter in general is able to precipitate lead, zinc and iron sulphides from solution, then any "peculiar efficiency" would be synonymous and interchangeable with "local abundance," for what one lacked in efficiency might be made up for by abundance, and vice versa. If, however, ordinary organic matter is not able to produce the ready precipitation of these metals from solution, then any "exceptional efficiency" may assume great importance. From this it follows directly, that whether or not the areal distribution of the ores is due to locally peculiar organic matter, leading to particular efficiency in producing precipitation depends entirely upon whether or not organic matter in general is able to cause the precipitation of the sulphides of lead, zinc and iron from solution. Inasmuch as iron sulphide

[1] Determination by C. W. Kenniston, Mining Experiment Station, Missouri School of Mines and Metallurgy.

is in general the least readily precipitated from a solution of these three metals, and inasmuch as iron sulphide is so commonly and characteristically associated with organic formations, such as the coal measures, it is believed that such field evidence indicates strongly that ordinary organic matter *is* able to produce the precipitation of these metals and, therefore, that "particular efficiency" has probably not been a prominent factor in controlling the areal distribution of the ores of this district.

It is therefore concluded that the areal distribution of the ores is not due to any one condition but, as is usually the case, to a combination of causes, probably all three of those listed above.

It is a striking fact that the non-glaciated area from which the Maquoketa shale has been eroded corresponds almost exactly with that of the lead and zinc district (see Fig. 90). There are, however, some discrepancies between the known mineralized area and the total area from which the Maquoketa shale has been eroded, especially in the north central portion of Illinois. The reason for this is not definitely known, but the following possibilities present themselves.

1. This portion of Illinois has not been accurately mapped and it seems probable that the Maquoketa shale is more extensive than indicated on the present map.

2. It is not definitely known that this area is not mineralized for ore has been found in a number of places beneath the drift to the south and east. If the area was as well mineralized as the richest portions of Wisconsin the chances that the ore, occurring under a heavy sheet of glacial drift as is present over this area, would have been found to date are very small.

3. It is possible that a considerable portion of this area was stripped of its shale by glacial action.

4. The Maquoketa shale may have had a different character over this area, or if the localization was due to local enrichment of sea near the mouths of streams, this area may not have been favorably situated.

With the exception noted above, there is a general agreement between the area from which the Maquoketa shale has been eroded

and that of the lead and zinc district. To the west the ores have been worked as far as the Galena dolomite has been exposed by the erosion of the Maquoketa shale. To the south along the Mississippi River ore occurs as far as Savanna and Mt. Carroll, where the shale is still present. To the east and north the district has been limited by the erosion of the ore-bearing formation, the

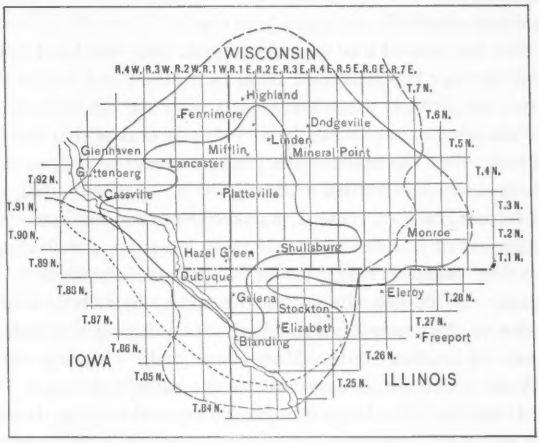

FIG. 90. Oil rock map. The outer continuous line marks the outer boundary of the area underlain by the oil rock. Where broken, boundary is uncertain. The inner continuous line incloses the area over which the oil rock averages a foot or more in thickness. (This thickness includes only the *pure* oil rock and not the interbedded clay and limestone which are often reported as oil rock.) The line composed of dashes marks the edge of the non-glaciated district, from which the Maquoketa shale, except in a few small places, has been entirely eroded.

Galena dolomite. The character of the Maquoketa shale under the thick sheet of drift to the east of the Wisconsin anticline is not known.

At the northern and eastern portions of the district ore has been found in the top of the Platteville limestone. This occurrence is thought to be due in general to ore having been carried

downward from the overlying formations during the process of secondary concentration. Ore is not found in this formation where it is not near the surface. The occurrence of small amounts of galena in the Lower Magnesian dolomite north of the Wisconsin River seems also to have been due to descending solutions inasmuch as the deposits are small, never in commercial quantities, and occur as fillings of openings directly connected with the surface and which die out quickly in depth.

Within the general lead and zinc region there are local mining districts more or less separated from each other, and within these local mining districts there are areas which are heavily mineralized while others are practically barren. It is true that the finding of new mines has made it practically impossible to draw sharp lines between some of these districts, but it is probable that, even in the future, some of these districts will remain distinct. Such segregations are believed to be due to an irregular distribution of the original metallic sulphides in the Maquoketa shale. The localization of the deposits within the minor districts is believed to be due to the concentration of solutions during the ordinary processes of erosion of the Maquoketa shale. During such a process of erosion hills and valleys are always formed. The water from the hills drain into the valleys where the drainage from a number of square miles may be caused to pass through a valley 10, 15 or 20 feet wide, thus producing a concentration of the solutions from a large area, especially where the underlying formation is impervious. These combined waters on passing from the Maquoketa shale sink into the fractures, joints, and pores of the Galena dolomite, where the ores contained in the solutions are subject to precipitation under favorable conditions. In this manner ore deposits a mile or even a number of miles apart may be simply and adequately explained.

The chief minerals associated with the lead and zinc ores are, in the order of their abundance, calcite, iron sulphide (marcasite and pyrite), barite and traces of copper ores. It is believed that the history of the copper and iron minerals is the same as that of the lead and zinc ores and hence needs no farther discussion

here. As a rule the introduction of the calcite was later than that of the ores of the first concentration, from which, together with the common occurrence of calcite gangues in limestones in general, it seems probable that the calcite was largely derived from the Galena dolomite, although the overlying shales do contain abundant calcium carbonate.

Barite occurs in the vicinity of Dubuque and Guttenberg, Ia., Platteville, Meekers Grove, New Diggings, Shullsburg, Mineral Point, Dodgeville, Monford, Wis., and in traces in practically all parts of the mining district. At the Gritty Six mine, SW. ¼, Sec. 21, T. 2 N., R. 1 E., where the barite is probably the most abundant, it contains small pieces of galena and is associated with large amounts of iron sulphide. The source of the barite may be either the Galena dolomite or the overlying Maquoketa shale as both contain barium compounds, but especially the shale. Clark's analyses[1] show that in general barium is present in greater amounts in shales than in limestones. Clark[2] farther states that P. P. Bedson[3] found barium to be present in notable amounts in an English colliery water; and T. Richardson[4] has described a deposit of barite from a similar solution. Like deposits from other English collieries have been reported by F. Cowles,[5] who analyzed samples containing from 81.37 to 93.35 per cent. of $BaSO_4$. The pipes carrying the water from the mines which yielded these sediments were often choked by them, the barium sulphate being rarely absent and frequently their chief constituent.

The average of three analyses of Maquoketa shale from Mt. Carroll and Elroy, Ill., and Graf, Ia., shows .031 per cent. BaO. Many pieces of barite as large as a small hen's egg are found in the Maquoketa shale, associated with the zinc blende and iron sulphide, at the Granville mine, near Scales Mound, Ill. Pieces of barite[6] weighing 6 or 8 pounds have been found at the Galena-

[1] Clark, F. W., "Analyses or Rocks from the Laboratory of the United States Geological Survey, 1880–1893, Bull. U. S. Geol. Survey, No. 228.

[2] Bull. U. S. Geol. Survey, No. 330, p. 498.

[3] *Jour. Soc. Chem. Ind.*, Vol. 6, p. 712, 1887.

[4] Rept. Brit. Assoc., 1863, p. 54.

[5] *Proc. Roy. Soc.*, Vol. 46, 1889, p. 368.

[6] Personal communication from John Babcock, Dubuque, Ia.

Maquoketa contact at Dubuque, Ia. The presence of such an abnormal amount of barium in the shale, and its general association (although in very small amounts) with the ores in all the districts and at all horizons in the Galena dolomite and the Maquoketa shale indicate that the ores and the barium have a like origin; while the presence of crystals of galena within the barite shows, at least, that the two have in some cases been precipitated at the same time.

The condition of the barium in the shale has not been determined, but it probably exists as both the carbonate and the sulphate. Because of the extreme insolubility of the sulphate, it seems reasonable to suppose that the barium was probably carried as the carbonate, which is soluble either in water containing CO_2 or in a solution of a bicarbonate. Water on pentrating the Maquoketa shale along some porous bed, as a seam of limestone or sandy shale, is soon depleted of its oxygen under these reducing conditions and becomes neutral or alkaline through the presence of the carbonates of the alkalies and alkaline earths. Such water would readily take into solution any barium carbonate present and carry it out of the shales at springs or by slow seepage, where it would be carried down over the remaining impervious shale and sink with the water into the openings of the Galena dolomite. Here, on meeting with solutions directly from the surface, oxidizing and acid with H_2SO_4 and its salts, precipitation of the barium as barite would occur.

If, however, the barium has been derived from the Galena dolomite, it has doubtless been carried in solution as a carbonate which entered the openings through the wall rock and there met the acid surface waters which caused the precipitation of the barium as barite.

It is not intended to discuss in this paper the structural features of the ore deposits except in so far as they are, or have been thought to be, related to the origin of the ores. Almost without exception the ore occurs along fractures which, although greatly enlarged by solution, have been caused and controlled by structural conditions. Inasmuch as the general character of these

openings has already been briefly discussed, it only remains to emphasize the explanation offered for certain features, especially the relation between the ore deposits and the oil rock basins, which have previously been advanced in favor of the Galena oil rock theory.

It has been pointed out that if the ore has been carried by water solutions anything which controlled these solutions would also control the ore deposits. If, therefore, as is natural, the water tends to flow downward into these impervious, pitching troughs and along the openings, such as the "verticals" and "flats and pitches" which occur most abundantly in these basins, it is most natural that the ore deposits formed by these waters should also show a tendency to occur in these basins. To prove that this relation between the ore deposits and the oil rock basins favors the proposed theory rather than that as proposed by Bain and others, it has been shown that there is, in many cases, thick oil rock without flats and pitches and without ore; that there is thick oil rock without the oil rock basins; that there are oil rock basins without ore; that, although most of the flats and pitches occur within the oil rock basins, some flats and pitches are found on the oil rock domes, or anticlines, as at the Dutch Hollow mine east of Potosi, Wis.; and that these flats and pitches are sometimes mineralized; also that one of the most famous mines of the district, the Baxter, is located on top of one of the most prominent anticlines in the district and that this deposit tends to follow down the slope of the hill (drainage slope). Moreover, it has often been shown, although apparently but little noticed, that a deposit of zinc connected with a deposit of lead near the surface, does not necessarily directly underlie the lead deposit, but almost invariably lies to the drainage side of this upper deposit, showing that the ore-bearing solutions were moving downward along the natural drainage channels. This is well shown by the Vinegar Hill mine north of Galena, Ill., and the Frontier mine at Benton, Wis.

It is therefore concluded that there is a close relation between the ore deposits and the structural features of the district, but

only in so far as these features have controlled the circulation of the ore bearing solutions and afforded openings in which the ores have been deposited. This question is the most important of those which now confront the mining men of the district and prospecting can not be carried on intelligently without its careful consideration.

SUMMARY.

In advancing the Maquoketa shale as the source of the ores it is not intended to convey the idea that these shales are the only formation in this district that contain original metallic sulphides. Traces of lead, zinc and iron sulphides are common in many formations, and it is believed that all the formations that are now or ever have been present in this district contained a small percentage of these compounds as original precipitates. Traces of sulphides, especially those of zinc and iron, have been found in such positions in the Lower Magnesian and Platteville formations as to suggest rather strongly that part of them at least is original in these formations. It therefore seems reasonable to suppose that the Potsdam sandstone, the Lower Magnesian dolomite, the St. Peter sandstone, the Platteville limestone, the oil rock, the Galena dolomite, the Maquoketa shale, and even the Niagara dolomite each contained at least a trace of these metallic sulphides as original minerals. It also seems probable that if this district was ever overlain by other formations, that they also contained some small amount of metallic sulphides.

Unquestionably the lead, zinc and iron ores originally came from pre-Cambrian igneous rocks, doubtless somewhere to the north where such rocks have been shown to contain these metals. They were taken into solution through the ordinary processes of erosion, carried to the sea by streams, and there deposited with the material of the Maquoketa shale, although in the time between their solution and deposition with the shale they may have been precipitated with other formations and later redissolved. After the deposition of the Maquoketa shale and such other formations as may have been laid down, the retreat of the sea, and the erosion of the overlying beds, the ore particles were again taken into solution by ordinary meteoric waters during the erosion of the

shale and carried downward and laterally into the porous and fractured Galena dolomite where precipitation of the ore occurred, due largely to the reducing action of organic compounds. In so far as secondary concentration has taken place after the introduction of the ores into the Galena dolomite, the ores were again taken into solution and carried downward to be precipitated in the same manner as before.

The Maquoketa shale is advanced as the probable source of the lead and zinc ores of this district for the following reasons:

1. The thickness of the shale, its organic content, and the high efficiency of its hydrocarbons as precipitating agents.

2. Lead and zinc have been found in such positions as to show beyond a doubt that they are original in this formation and in quantities adequate to account for the ore deposits.

3. This hypothesis of source explains the vertical distribution of the ores and the order of their deposition upon the wall rock without appealing to secondary concentration.

4. It accounts for the areal distribution of the ores, the location of the district and especially the variations within it.

5. It accounts for the associated minerals as well as for their distribution.

6. It accounts for such ore deposits as the Baxter and Dutch Hollow mines, situated on top of oil rock ridges, as well as for those deposits which occur in the bottoms or on the limbs of the oil rock basins.

7. It accounts for ranges and the marked tendency for the ore deposits to favor valleys.

8. It accounts for the large excess of the zinc over the lead mined in the northern portion of the district, where it occurs in the lower portion of the Galena dolomite, and the excess of the lead over the zinc in the southern portion, as around Dubuque, Galena, Stockton and Elizabeth, where the separation of the lead from the zinc has been more marked, the later ore occurred near the top of the Galena formation.

9. It is believed that it accounts for all the features of the ore deposits in a manner more simple and complete than any hypothesis heretofore proposed.

A NEW DIAMOND LOCALITY IN THE TULAMEEN DISTRICT, BRITISH COLUMBIA.

CHARLES CAMSELL.

In March, 1911, an announcement was made by the Director of the Canadian Geological Survey in the daily press of a discovery of diamonds made in the peridotite of the Tulameen district of British Columbia. For parts of the seasons of 1909 and 1910 geological field work had been carried on in that region by the author and a report and map of the district in now in course of preparation. Specimens of chromite obtained from the peridotite were examined by Mr. R. A. A. Johnston, mineralogist to the Survey, with the result that diamonds were discovered in them. This is the first recorded discovery of diamonds in Canada that the Survey can vouch for, and the second instance in which these gems have been found in the original matrix on the North American continent.

The exact locality from which the diamonds were obtained is Olivine Mountain, which is situated on the south side of the Tulameen River and rises about 3,000 feet above that stream. The locality is about thirty miles north of the international boundary line, and about twenty-five miles directly east of the Fraser River at the town of Hope. It it not accessible from the west, as it lies on the eastern flank of the Cascade range which at this point has no easy route through it. It can, however, be reached from the end of the Great Northern railway line at Princeton by a drive of about twenty-five miles; or from the Canadian Pacific railway at Nicola by a longer drive of about sixty miles. The former route is preferable.

GENERAL FEATURES AND DISTRIBUTION.

Although placer mining in many of the streams of the Tulameen district has been carried on for a number of years, the

presence of diamonds in the gravels has never been demonstrated and consequently it was not suspected that they would be discovered in any of the rocks from which these gravels have been derived. For many years, however, officers of the Geological Survey working in British Columbia have been on the lookout for diamonds and have warned prospectors of the possibility of finding them in the placers. Several years ago the present Director of the Survey drew the attention of miners to the necessity of observing carefully those placers which were derived from the erosion of such basic rocks as peridotite, and expressed the belief that diamonds might occasionally be found in them.

In the course of the mapping and examination of the body of peridotite which extends from Olivine Mountain across the Tulameen Valley to Grasshopper Mountain, masses of chromite were observed in several places in the peridotite. Hand specimens of this chromite imbedded in serpentinized peridotite were brought in and handed to Mr. R. A. A. Johnston, mineralogist to the Survey, to determine the nature of the chromite. In the course of his analysis Mr. Johnston obtained a residual product from fusion which proved on examination to be diamonds, yielding positive reactions in all the tests for that mineral. Further tests were made in New York by Dr. G. F. Kunz who confirmed the discovery. This is the first recorded discovery of diamonds in Canada, that the Survey can vouch for.

So far as our knowledge of the occurrence yet goes, the diamonds are associated with the chromite and are not found in other parts of the rock mass, so that their distribution depends upon that of the chromite. The chromite itself does not occur here in large bodies and its distribution is very erratic.

The diamonds obtained from the samples analyzed are small, though their quality is excellent. They have proved very difficult to extract from the rock without being broken, and even after extraction they often break up in the course of a few hours or days into much smaller fragments. For these reasons it is doubtful if the occurrence is of any commercial importance, though it is of great scientific interest.

It is very probable that in the course of placer mining of the gravels of this district some diamonds have been overlooked and discarded, and with a more careful examination in the future of the concentrates obtained in washing for gold and platinum, it is likely that some may be obtained. The materials found in the gravels are derived from the solid rocks by the slow process of natural erosion, and the slowness of this action would tend to preserve the diamonds in their original size and form, so that diamonds of a larger size than have so far been extracted from the rock may possibly be found in the gravels.

These placers are in any case valuable for their gold and platinum content and are likely to be worked for these products alone; so that while placer mining for diamonds alone might not be a profitable undertaking, if any are recoverable from the gravels they add just that much to the value of the gold and platinum placers. Even fine material, if it could be saved, would have a value as diamond dust.

MATRIX.

The matrix of the diamond is a peridotite of the variety dunite. It occurs as an intrusive igneous stock about three miles long and a mile wide bordered on all sides by pyroxenite into which the peridotite passes by a gradual change in composition. The two rocks are of the same age and have been thrust through rocks of presumably Triassic age consisting of volcanic materials and a few thin beds of argillite and limestone.

Over a great part of its area the peridotite consists of olivine only. Chromite enters in isolated places but rarely occupies a more prominent position than that of an accessory constituent in the rock. It then appears either sparingly disseminated through the peridotite or as segregations in short veins or bunches. These segregations are rarely more than an inch in width and a few inches in length. It is not evident that they are confined to any particular part of the peridotite mass, though in many other peridotite bodies such segregations of chromite have been found to be situated nearer the borders of the body than in its central parts. Magnetite occurs more sparingly than the chromite.

Practically all the samples of peridotite collected from this body show signs of alteration to serpentine. The freshest samples when seen under the microscope show cores of olivine separated by small veins of serpentine. In the extreme cases no olivine remains and there is left only a dense mat of serpentine fibers.

	Tulameen Peridotite.		Arkansas Peridotite.[2]	Kimberley Blue Ground.[3]	New South Wales Hornblende Diabase.[4]
	No. 1.	No. 2.[1]			
SiO_2	33.48	33.40	38.73	39.732	50.43
Al_2O_3	1.50	.29	6.85	2.309	14.72
Fe_2O_3	7.27	3.42	8.83		2.90
FeO	1.36	6.69	1.99	9.69	4.59
MgO	42.02	45.23	26.34	24.419	6.67
CaO	0.02	.35	3.88	10.162	7.13
MnO	.06	.24			0.03
$K_2O + Na_2O$	.29	.08	3.34		3.70
$H_2O +$	.60	.24	1.05		3.49
$H_2O —$	13.26	4.11	7.85	7.547	3.82
CO_2		1.10	.14	6.556	1.67
TiO_2	trace		.89		0 82
P_2O_5		trace			0.22
S		.06			0.01
Cr_2O_3		.07			0.02
NiO		.10			
V_2O_5					0.03
	99.86	100.38	100.84	100.415	100.25

[1] U. S. G. S. Bull. No. 193.
[2] Geol. Surv. of Arkansas, 1890, Vol. II., p. 377.
[3] "Precious Stones," by Bauer and Spencer, p. 190.
[4] British Assoc. for Adv. of Sci., 1906, p. 562.

In structure it is massive and shows little evidence of being disturbed by dynamic movement. It is not brecciated and only to a limited extent sheared. It does not break down easily, but when it does it forms a talus of small flat chips. Surface decomposition generally only extends for about an inch in depth, and in weathering rounded or spheroidal shapes are developed.

The peridotite has the form of a stock elongated in a general north and south direction, and is cut through almost in the middle by the Tulameen River which exposes a section of it about 3,000 feet in height.

Two chemical analyses of the Tulameen rock are given below, showing different stages of alteration to serpentine. For the purpose of comparison the analyses of three other diamond-bearing rocks are also given.

The matrix of the Tulameen diamonds is similar to that in which diamonds have been found in Pike County, Arkansas, and from which up to July, 1909, over 700 commercial diamonds had been recovered. This rock is described as a peridotite occurring in a stock covering about 60 acres and thrust through Carboniferous sandstones and quartzites.[1]

The Kimberlite of South Africa is also a related rock, and its occurrence in pipes indicates a similar origin to that of the Tulameen peridotite. The main difference in both the Arkansas and the South African matrices is in the degree of alteration and decomposition that has taken place, a decomposition which in the Tulameen rock extends only to the depth of an inch or two, but in the other instances to many feet.

The most common matrix of the diamond appears then to be rocks of extreme basic composition. There is, however, an instance recorded by Prof. T. W. E. David[2] of diamonds, occurring in a slightly more acid rock. This rock is described as a hornblende diabase occurring as a dike cutting granite at Oakey Creek, New South Wales, the diamonds having been found imbedded in the rock.

The Tulameen occurrence is only the second instance in which diamonds have been found in the original matrix on the North American continent, the Arkansas occurrence being the first.

ASSOCIATION AND MODE OF OCCURRENCE.

In the course of chemical analysis of the sample submitted to him, Mr. Johnston found that the diamond was associated with the chromite rather than with the serpentine. A small piece of chromite was taken and ground in a mortar and then separated into two parts—a magnetic and a non-magnetic part. The magnetic portion was found to contain about 6 per cent. of diamond,

[1] Economic Geology, Vol. III., p. 525, 1908.
[2] British Association for the Adv. of Sci., 1906, p. 562.

while the non-magnetic part carried about 3 per cent. Platinum and a smaller quantity of gold were also found to be associated with the chromite.

If it is true that the diamonds only occur with the chromite, the quantity of diamond in the rock will depend on the amount of chromite present. As the discovery of diamonds was only made after the completion of field work in the Tulameen district, it is impossible to say, except in a general way, what proportion of chromite there is to the olivine in the peridotite. From a general survey of the peridotite in the field and a more precise examination of the thin sections, the conclusion was drawn that the chromite forms a very small proportion of the rock, and except when segregations occur is almost a negligible quantity. The segregations are either bunches or short irregular veins formed at the time of intrusion of the rock. The veins vary in width up to one inch in diameter, are not continuous in length for more than a few inches, and branch out into a number of smaller interlocking veinlets. Their walls are irregular lines and are not always clean cut. Both the veins and the rock are traversed by small lines of dislocation.

The presence of platinum in the chromite segregations had previously been determined by assay when .02 ounces of platinum to the ton were obtained. It was again identified under the microscope in the product derived by fusion from the chromite. In the latter case a quantity amounting to almost two ounces to the ton was obtained. A smaller quantity of gold was also found to be present.

MINERALOGY.

A careful examination of the peridotite with a hand lens has not yet resulted in the identification of any diamonds in it. The first results were obtained by Mr. Johnston by fusion in a crucible. Since then a sample of chromite from the same hand specimen which yielded the diamonds was taken and thin sections cut from it. In at least four of the thin sections diamonds could be identified under the microscope.

These thin sections show massive opaque chromite, traversed

by narrow veinlets of serpentine associated with short fibers of hornblende. The diamonds occur as a rule in the narrow veinlets.

In general appearance the diamonds are brownish to yellowish in color, partly or wholly opaque, and having a spherical or quite irregular outline. They frequently though not always abut against the chromite. They have a high relief and are generally isotropic. Some show optical anomalies. In reflected light they give a brilliant display of colors, which come from a number of small points in the material. Examined under the high power the brownish areas of diamonds are seen to be not single individuals, but to be small dust-like particles grouped together in aggregates. It is the grouping of these small particles together in aggregates that gives the great variety of colors in reflected light. These aggregates are more properly called bort.

Besides these aggregates small octahedra are occasionally seen associated with the chromite. These are clear and bright in transmitted light, have a high relief and are idiomorphic towards the chromite. Their outline is sharp, and they have undoubtedly crystallized before the chromite with which they are associated. They are translucent, and in reflected light give a strong play of colors. Between crossed nicols they are quite opaque and therefore isotropic.

The product obtained by Mr. Johnston from fusion shows the two varieties already described, one being a yellowish massive substance, and the other small well-crystallized individuals of apparently great purity. Octahedral forms are very common with sharp outlines and clean-cut faces. Many of them show striations on the octahedral faces, and twins are common. Under a very high power the small individuals are seen to hold inclusions, either liquid or gaseous.

The largest individuals so far obtained by Mr. Johnston are about the size of an ordinary pin's head, but in a great many cases these individuals break up on being released from the rock into smaller particles which are rarely more than three tenths of a millimeter in the long diameter. This happens often within an

hour or two, and is quite noticeable inside of a week. It is probable that the breaking up may be due to the inclusions.

GENESIS.

Much of the evidence on which to base conclusions on the genesis of these diamonds has already been stated. For the sake of clearness a recapitulation of this is given here together with certain other points which have not heretofore been mentioned.

In the first place there can be no doubt of the igneous origin of the rock which forms the matrix of the diamonds. In this rock the diamonds are associated with the chromite in such a way as to force one to the conclusion that both are primary constituents of it. The thin sections show these two minerals to be very often in contact with each other, and where crystalline individuals of diamond were identified they were seen to have distinct crystallographic outline and to be idiomorphic towards the chromite, showing that in crystallizing the diamond formed first, and the chromite had to adjust itself to the shape of the diamond. There is no evidence to show that the diamonds were introduced later than the chromite; and the chromite of such dunites is accepted by all geologists to be of magmatic origin. A few investigators believe that under certain circumstances and to a limited extent chromite migrates in solution but in such cases the conditions of occurrence are different. If then the chromite is an original constituent and a segregation from a cooling magma then diamonds must have originated in the same way.

The matrix of the diamonds is intrusive through a series of rocks that contains little or no carbonaceous matter, and in fact largely volcanic in origin, so that the carbon could not have been derived from them. In fact the only carbonaceous rocks in the district are of Tertiary age and are much younger than the diamond-bearing rock. The present occurrence of diamonds, therefore, in no way supports the theory of an organic origin for the carbon necessary to form the diamonds. It is more probable that the carbon existed in some form as an original constituent of the peridotite magma, and on solidifying crystallized out as diamond.

REVIEWS

Chrysotile-Asbestos: Its Occurrence, Exploitation, Milling and Uses. By FRITZ CIRKEL. Second edition, enlarged. Monograph No. 69. Canada Department of Mines, Mines Branch, 1910. Pp. 316. 88 figures, 2 maps and 56 plates.

This new edition is almost wholly rewritten and the work has doubled in size within five years of its first publication. From the beginning the volume is attractive. Considering its comprehensive but concise title the reader may be surprised at the size of the book, but the stout paper covers, strong binding, fine paper, neat type and good illustrations, all improvements on the first edition, prepossess him in its favor and he begins the perusal with pleasure which continues to the end of the volume. The work clearly presents the various phases of the most important mining industry of the eastern provinces of Quebec and will be welcomed by many who are interested either directly or indirectly in the development of asbestos elsewhere.

In the preparation of this new edition special attention was given to mapping the productive areas of the serpentine belt and to determining the depth of the asbestos deposits. Additional light has been obtained on the origin of asbestos and photomicrographs are used to show the mineral composition and structure of the rock with which the asbestos is associated. The surface openings from which the material is won were called mines in the earlier edition but in the present edition are termed quarries, in accordance with the more common usage.

The scope of the monograph is indicated by the eight chapter headings and includes, besides historical matter, accounts of the properties of asbestos, the Canadian serpentine areas and productive serpentine range, quarrying asbestos, dressing it for market, the mines and prospects of Canada, those of foreign countries, and finally the commercial applications of asbestos with an appendix by Frederic Bacon on the testing of heat-insulating materials.

The first chapter begins with a succinct account of the discovery and more important historical applications of asbestos from the time of the ancient pyre down to modern times, giving special attention to the development of the industry in Canada, where when the book was written there were in operation fifteen quarries and nineteen mills which furnished over 80 per cent. of the asbestos supplied to the world's market.

The consideration of asbestos minerals is replete with interesting observations. Numerous chemical analyses are given and it is shown that good commercial fiber, be it hornblende like the Italian product or chrysotile like the Canadian, contains at least 13 per cent. of water, while all the harsh brittle fibers contain less than 5 per cent.

Many observers have contributed to the knowledge of the geology of the serpentine areas of Canada. Some chrysotile asbestos has been found in the Laurentian and Huronian serpentines, but its principal occurrences are in the Cambrian serpentines which occupy a belt of three more or less distinctly separated areas extending from Gaspé peninsula southwest across the eastern provinces of Quebec into Vermont. The middle area, about 23 miles in length including Thetford and Black Lake, is the richest and is distinguished as "the great vein fiber belt." In the southwestern area which crosses the international boundary there are large quarries at Danville only.

A number of photomicrographs are used to illustrate the mineralogical composition and structure of the original rocks which are briefly described by Dr. Alfred W. G. Wilson. The rocks range from dunite and pyroxenite to gabbro and diabase, but no attempt is made at systematic petrography.

Adjoining the asbestos veins the rock is completely changed to serpentine, but a few inches away residual grains of olivine and pyroxene are still preserved. Upon this point Dresser[1] has made the interesting observation that the serpentine extends on both sides of the vein to a width of about three times that of the vein.

Vein fiber and slip fiber is a general heading under which the two types of chrysotile are considered. Most recent writers agree in using the term slip fiber, but as to the use of the term vein fiber in contrast with slip fiber there is objection in the reviewer's opinion for the reason that slip fiber in some if not in all places occurs in veins. It is then both slip fiber and vein fiber. Marsters'[2] term *cross fiber* is much more distinctive than vein fiber, and having been used by Barlow,[3] Richardson,[4] and others[5] deserves wider recognition. Vein fiber in contradistinction to mass fiber may then be classified as cross fiber and slip fiber.

The productive range from Broughton to Danville is mapped on the scale of an inch to a mile so as to show the outlines of the serpentine

[1] *Canadian Mining Journal*, June 1, 1909, p. 338.
[2] *Bull. Geol. Soc. of Am.*, Vol. 16, p. 433, 1905.
[3] *Quart. Bull. Can. Min. Inst.*, No. 12, October, 1910, p. 116.
[4] Seventh Report Vermont Geological Survey, p. 320, 1910.
[5] U. S. Geol. Survey Min. Resources, 1906, p. 1124, and *Jour. Can. Min. Inst.*, part of Vol. XIV., p. 49, 1911.

which did not appear in the first edition, as well as the location of 23 mills, 40 quarries and 55 prospects.

The great vein fiber belt of Thetford and Black Lake is the richest in cross fiber veins. The same body of serpentine contains masses of chromite and dikes of granitic rocks. It is strongly contrasted with the Broughton area that is distinguished by slip fiber with neither masses of chromite nor granitic dikes.

The total area of the vein fiber belt of serpentine is estimated at 17,300 acres. Allowing for the area of chromic iron ore and 10 per cent. for granitic and other intrusives the total acreage of the vein fiber belt is 12,420, of which only 1,100 acres are under development at the present time.

Much attention is given to the origin of asbestos, and to express his views more clearly the author gives the following tabulation of the "successive changes which the original rock in all probability underwent."

Broughton. Thetford-Black Lake.

1. Intrusion of olivine (dunite) through the earth crust from below.
2. Gradual alteration of the rock to serpentine through hydration, and perhaps loss of silica, increase in volume.
3. Slow readjustment of the rock-masses, resulting in the formation of joints and slickensides.
4. Subsequent formation of fissures as receptacles for asbestos fiber through shrinkage of the rock, and also through injection of granite dikes.
5. Infiltration of serpentinous solution from the sides of the wall through process of segregation and subsequent slow crystallization of chrysotile.
6. Second slow readjustment of the magmatic rock mass and the formation of 'slip' fiber."[1]

Much interest attaches also to the view of John A. Dresser who[2] regards the veins of chrysotile as due in large measure to replacement of serpentine along joints. Microscopical investigation may be expected to furnish important evidence for final conclusions.

Asbestos has been found to the depth of 400 feet, but in view of theoretical considerations concerning the origin of asbestos Dr. Cirkel ventures the opinion[3] that these workable asbestos deposits extend to considerable depth, probably to several thousand feet, and quotes Mr. John A. Dresser who states that "except for the possibility of reaching the floor of a sheet it is safe to conclude that the asbestos deposits of

[1] P. 101.
[2] *The Journal of the Canadian Mining Institute*, Vol. XII., 1909, pp. 170–171.
[3] P. 102.

the eastern townships will continue for as great depth as they can be profitably mined."

Quarrying asbestos and dressing it for market are fully treated with numerous illustrations most helpful to those who are engaged in the industry and the cost of plant and equipment as well as of extraction are noted.

While the crude in the richest mines can be put down as from 0.25 to 0.75 per cent. of the total rock mined, the rock milled ranges from 20 to 80 per cent. of the rock quarried and in the Thetford-Black Lake region the extraction of fiber is from 6 to 10 per cent. of the rock milled.

After description of the mines and prospects of Canada a comprehensive account is given of the asbestos of foreign countries, and the dominant position of Canada in the world's supply becomes evident. In 1908 it furnished 82.6 per cent. of the total supply, and Russia came next with 14.4 per cent. The production of the United States is given as about 1 per cent. of the Canadian. Since then it has increased. In 1910, considering all grades excepting asbestic, the production in the United States was about 4 per cent. of that of Canada.

The author, having been in the employ of the Bureau of Mines and later a mining engineer of the Amalgamated Asbestos Corporation, limited, has had the best opportunity to get at the facts. The volume is certainly a most welcome and valuable addition to literature of asbestos.

J. S. Diller.

SCIENTIFIC NOTES AND NEWS[1]

THE AMERICAN INSTITUTE OF MINING ENGINEERS will hold its 101st meeting in San Francisco, Cal., October 10th to 17th. A special circular giving the detailed itinerary of the excursion to Japan and other information concerning the trip has been issued by the American Institute of Mining Engineers.

PROFESSOR C. K. LEITH, of the University of Wisconsin, has been engaged for two months in estimating iron ore reserves of Michigan for the Michigan State Tax Commission. This was a part of the general appraisal of the mining industry of the state, under charge of Mr. J. R. Finlay of New York City. This appraisal was authorized by a special act of the Michigan Legislature in its last session.

LOUIS DOREMUS HUNTOON, for the past seven years Professor of Mining and Metallurgy at the Sheffield Scientific School of Yale University, has opened offices at 42 Broadway, New York, for the general practice of mining engineering.

GEORGE H. GARREY, mining geologist and engineer, formerly economic geologist with American Smelters Securities Co., American Smelting and Refining Co., Guggenheim Exploration Co., and recently Manager Southern Division of Spurr & Cox, Inc., wishes to announce that he has opened an office in San Francisco, as Consulting Specialist in Mining Geology.

J. B. TYRRELL, of Toronto, has returned from a short visit to London, England.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

GEORGE OTIS SMITH, Director of the United States Geological Survey, recently delivered an address on the Mining Industry and the Public Lands: Necessary Amendments to the Mineral Laws, at the 21st Anniversary of the Michigan School of Mines, Houghton, Mich.

MR. WALDEMAR LINDGREN, of the U. S. Geological Survey, has returned from the west where he has been making a study of the ore-deposits of Tintic, Utah.